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HUMAN PHYSIOLOGY

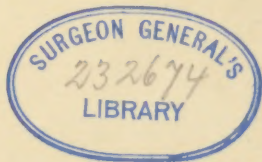
A Text-Book for High Schools and Colleges

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TO MY FATHER
EDMUND ELY STILES
A DAUNTLESS OPTIMIST

PREFACE TO THE SECOND EDITION

ASIDE from the chapter on Reproduction the new material in this edition consists less in added facts than in fresh ways of marshalling the data originally included. I am in full agreement with my distinguished reviewer, Professor W. M. Bayliss, of England, that it is only too easy to sacrifice clearness of essentials to multiplicity of details. The teacher whose task year after year is to introduce successive classes to the fundamentals of his subject will probably find with the passing of time that he is telling them less and less about the science, though it may be reasonably hoped that he is telling it better.

The distinction between elementary and advanced presentations which was dwelt upon in the Preface of 1916 becomes more marked as the literature accumulates. Recent contributions to Physiology are largely of a quantitative character. From this time forth the masters of the branch must be men thoroughly grounded in Electricity and Physical Chemistry. Those of us who once turned to Physiology with the serene confidence that it would never involve us in any mathematics have come to a time of disillusioning. But the unfolding of the story in qualitative terms is a work which must still be done.

P. G. S.

BOSTON, MASS.,
February, 1919.

PREFACE

TEXT-BOOKS of science may be placed in two classes. There are those which aim at fullness of statement and seek to acquaint their readers with experimental methods and original sources. Such books must give a large place to controverted matters, weighing conflicting evidence and comparing the views of various workers. The making of them is properly in the hands of great masters of the several branches.

Other books have a more modest scope. Their purpose is to present concisely the accepted facts with only a limited description of the experiments by which these facts have been established. They contain comparatively little about unsettled questions though they are at fault if they do not make it plain that these confront the investigator at every turn. They may be written by teachers who have not lost the point of view of elementary students or ceased to sympathize with them in their perplexities.

The present book belongs definitely to the second class. An extreme course of action has been adopted with regard to the accrediting of discoveries. It is certainly a source of irritation and bewilderment to the beginner to have the pages he reads sprinkled thickly with the names of men of whom he has never heard before. In the chapters that follow no mention is made of living experimenters though a few eminent physiologists of earlier times are referred to. It has been hard not to make exceptions and the use without acknowledgment of illuminating ideas and happy teaching devices which I owe to my contemporaries has aroused a feeling akin to guilt. Some atonement may be found in the list of collateral readings at the end of the book.

P. G. S.

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HUMAN PHYSIOLOGY

TO THE TEACHER

It is commonly assumed that the chief qualification for the teaching of physiology is a knowledge of anatomy. Indeed, what is called physiology in the lower schools has often been a mere description of the organization of the body. Anatomy can evidently be taught without reference to other sciences and the instructor who follows the line of least resistance with regard to his own preparation is likely to give a large place to the pictorial branch. But the temptation is one to be resisted. It is a sound principle to subordinate details of structure to the facts of operation.

It is much more important that the teacher shall be adequately grounded in physics and chemistry than that he shall be an authority on anatomy. The difficulties experienced by the student are not connected with shapes, appearances, and arrangements which he can visualize but with molecules and forces. The teacher must assist him here and must bring to his task well-ordered knowledge of these things. The central conception must be the transformation of energy by the living tissues.

Physiology can be taught to the best purpose to pupils who have had previous courses in both physics and chemistry. In the introduction to this book it is pointed out that physiology could not develop historically until these sciences were well advanced. It is legitimate to argue that it cannot be grasped by the individual without the elements of these supporting sciences to serve as its foundation. The next best thing to having these subjects

precede physiology is to have them simultaneous with it. If only one can be taken the choice must fall on chemistry.

The teacher who is called upon to give a course in physiology to students who have had neither physics nor chemistry is severely handicapped. They must soon be using phrases which cannot mean to them what they mean to others of ampler training. They may recite glibly and to the satisfaction of an easy-going instructor, but the large conceptions may be wanting. A teacher who has to make the most of such a situation will be compelled to sacrifice much in other directions to secure clearness as to fundamentals. Detail, however attractive, must give way to cardinal truths.

What are the matters which must be impressed at any cost? First of all, the conservation of energy and its convertibility from one form to another. Second, the closely related fact of the latency of energy in those compounds which we call fuels. The recognition of food as a biologic fuel. The general significance of oxidation and the release of potential energy. The realization that the respiratory process is a particular case of oxidation and that its value is in the setting free of energy that becomes manifest as heat and mechanical work. Finally, the conception that the development and application of energy are determined by stimuli brought to bear upon organisms from the world without.

Attention may be called to one of the many sources of confusion which troubles beginners. This is the question of *scale*. The student has thought almost altogether in the past of things which are appreciated by the naked eye. When he enters upon his study of physiology he may be said to be asked to conceive of three orders of magnitude. The features of gross anatomy present no difficulty. But these are pictured on one page of his book while on the next there may be a representation of cells. The teacher must be at pains to make plain what ratio obtains between the two.

The following device may be helpful. A fine hair may

have a diameter of $\frac{1}{500}$ inch. Six red corpuscles, lying flat in a row with their edges touching, would about span the cut end of the hair. It would take half a dozen bacteria of average size, laid end to end, to reach across the disc of a single red corpuscle. When the microscope is used, it is a convenience to bear in mind the real size of the visible field. For a magnification of 100 diameters this is usually about $\frac{1}{20}$ inch; for 500 diameters it is about $\frac{1}{100}$.

At the same time that the pupil is required to think in terms of microscopic measurements he is introduced to molecular and atomic ideas. He is in danger of failing to realize how great is the difference in scale between the two. He must not be allowed to think that the microscope can bring the molecules of a true solution to visibility. The effort must be to explain to him that this is utterly beyond accomplishment. The step from the gross structure to the cellular is short indeed compared with the further transition to the realm of molecules.

A word about helps in teaching. A first-class manikin is a treasure greatly to be desired. Its superiority to charts and diagrams lies in its solidity, its representation of three dimensions in the only convincing way that can be employed. However, a good manikin is expensive. Those which are flat and made to unfold, layer after layer, are not realistic enough to be preferred to charts, and charts in turn may be dispensed with for most purposes if the teacher will cultivate blackboard drawing. The great advantage of chalk lies in the fact that whatever feature is under discussion may be made to stand out and no details which are not helpful at the moment need be in view. It is much easier to follow the exposition when the structures referred to appear successively than when they are all presented at once as in a completed figure.

The teacher of physiology must take a middle course in the endeavor to correct two extreme tendencies commonly manifested by immature students. The very same

attitudes have been illustrated by profound thinkers. A pupil of one type will underrate the complexity of the problems he hears about and will become a mechanist of the crass and confident sort. Another will doubt the value of all attempts to penetrate such an intricate maze. To the temperate mind there should be apparent at one and the same time the profit that will continually accrue from research and the unlimited extent of the work still to be done.

The last chapter of this book has the character of an appendix and is designed more for the teacher than for the student.

CHAPTER I

INTRODUCTION

Physiology and Other Sciences.—Physiology has been well defined as “the physics and chemistry of living matter.” If this is a fair statement it is a peculiarly advanced and difficult sort of physics and chemistry, for it has to do with reactions and compounds of the most complex description. It could not be developed far until the physics and chemistry of non-living matter had prepared the way. Another science also had to come before it, namely, anatomy, the study of the structure of organisms. This was a field in which progress could be made independently of other discoveries and it is not strange, therefore, that so early as the sixteenth century a large mass of anatomic knowledge was embodied in monumental books with finely executed plates that still command admiration. The principal object of study and delineation was the human rather than the animal organization. In the next century anatomy became broadly comparative, extending to many forms, and at the same time it became minute, such poor microscopes as were available being diligently employed.

But the seventeenth century is most likely to be associated in our thought with Descartes and Boyle, Galileo and Newton, men who were preëminently physicists or astronomers. The contemporary chemistry was limited and confused. It was natural that the great addition to physiologic knowledge made in this period should have been in the realm of physics. This was the conception of the circulation of the blood. The arguments in support of the doctrine were marshalled by William Harvey in 1628 in such a telling fashion that it was soon universally accepted. Just about a hundred years later the

problems of the circulation were skillfully investigated from a quantitative point of view by another Englishman, Stephen Hales. In general, however, physiology in the seventeenth and in a large part of the eighteenth century consisted mainly of inferences drawn from anatomic structure. Sometimes these were exceedingly shrewd while others were recklessly speculative.

Late in the eighteenth century the science of chemistry was rapidly advanced and physiology at once began to profit by the new knowledge. This was particularly true in the investigation of respiration, the comparison between living organisms and other agencies of oxidation, and in a new appreciation of the nature of digestive processes. It was at this time that a fundamental principle was recognized in the indestructibility of matter, the teaching that substances may be transformed in many ways but never annihilated. This was prophetic of the doctrine of the conservation of energy which was to be established seventy-five years later and which has been almost as influential in biology as in physics.

We may estimate as highly as possible the accumulation of physiologic facts before the year 1800, and we shall yet feel that our science belongs essentially to the nineteenth century. Many of its cardinal discoveries are referred to dates between 1840 and 1870. The middle of the century found the chemistry of organic compounds well developed and at the disposal of the physiologist. Johannes Müller (1801-1858) has been called the "Father of Modern Physiology." A brilliant contributor himself, he was the teacher of a group of distinguished workers who diverged into various fields to multiply observations of the greatest interest. The influence of Müller in Germany was perhaps equalled in France by that of Magendie and his eminent successor Bernard.

Physiology is still unfolding. At the present time there are many laboratories where its problems are under scrutiny and journals in several languages appear each month. The literature has become so large that it has to be compiled and presented in volumes of abstracts.

Those who are pursuing researches in the chemistry of living things are more and more definitely separated from those whose studies are physical. It is scarcely possible to be an authority in both subdivisions. Specialization constantly becomes more pronounced. For example, the subject of the electric phenomena which can be observed in living tissues is extensive enough by itself to engage the exclusive attention of many students.

Methods in Physiology.—Something must now be said of the methods which physiologists employ. Evidently they must work upon living matter since their interest is in the reactions which are peculiar to it. It does not follow that they always make use of intact organisms for the living state may often be protracted for some time in portions of animals (or plants) detached from the body. Thus the muscles of a frog's leg can be preserved for hours after separation from the other systems and will behave in much the same way as if they were still united with them. This property of "survival," which is so valuable to experimenters, is much more to be relied on in the so-called cold-blooded than in the warm-blooded animals.

For carrying out many researches it is necessary to use living animals. We must frequently mention such procedures in the course of this book and it will be well at the outset to speak briefly of vivisection and the objections which are raised against it. It is not strange that experiments on animals should be viewed with abhorrence by those who have been influenced by the highly colored accounts of scientific misdoing which are so widely current. The feeling of compassion and the impulse to protect all creatures from suffering are so admirable that the physiologist must have a certain sympathy with his most violent critic. Nevertheless he feels that the opposition to his methods is due mainly to ignorance of actual conditions and misapprehension of the spirit of the investigator.

A prime fact to be reckoned with is that physiologists

are as humane as other educated men and as reluctant to inflict pain. The contrary assertion is familiar, but it may be questioned whether it has ever been made by anyone enjoying a wide acquaintance among such workers. In the second place, the physiologist can almost always avoid giving pain and actually promotes the success of his work by excluding it. Pain would be a disturbing factor in most experiments and the most cold-blooded scientist would have reason to prevent it. Many years ago, when there were no anesthetics to be used, animals were certainly made to suffer severely that physiologic knowledge might be advanced. The results of the early work have proved so valuable that we are glad that it was done; at the same time we congratulate ourselves that the work can be continued without the infliction of pain.

It is sometimes urged that we have no right to deprive animals of life or liberty for scientific ends. This cannot well be maintained with any show of consistency unless the advocate is a vegetarian. We can do without meat and it will hardly be claimed that we are justified in destroying animals for the gratification of appetite and not for the increase of knowledge. Most humanitarians recognize the necessity of doing away with superfluous animals and make this a prominent function of their organizations. The subjective experience of a dog or cat killed by ether or chloroform could not be different if an operation were performed upon it before it died from what it would be if the anesthetic were at once forced to a fatal intensity.

In exceptional cases animals are allowed to recover from anesthesia and are kept alive to observe the later effects of an operation. This may sometimes involve suffering, but it may also be the only way to discover important truths. It is a fact that such experiments are performed with genuine reluctance by the typical physiologist and in a spirit like that which animates any other surgeon. Whatever hardship may have been imposed

upon animals in our laboratories cannot for a moment be compared with the thoughtless cruelty of hunters and, in the writer's opinion, with the abuse of pets by children.

Vivisection has been effectively defended on the ground that it has been indispensable to medical progress. This argument will not be extended here but the question asked by a great surgeon—W. W. Keen—may be repeated for the consideration of the reader: "Reckoned in rabbits, what is the value of your wife, your husband, or your child?"

The Mechanistic Conception.—Experimenters of the present time believe that the organisms with which they have to do are mechanisms in the sense that none of the recognized principles of physics and chemistry are violated in their working. This conception is held in place of an earlier one, now spoken of as that of the *Vitalists*, according to which living things were regarded as unique in character and not bound by all the limitations of strict mechanisms. Of course it is recognized that there is an abundance of mystery about life and its manifestations, but all progress toward a better understanding of plants and animals has thus far been based on the view that they exemplify the same laws which are accepted as applicable to things not living. While this is true it is probably correct to say that the physiologist of to-day has a more adequate realization of the complexity of his problems than his predecessor had a generation ago. It must be borne in mind that, except for certain passages in the treatment of the brain, the point of view is objective, that is, the concern is with what happens in a material body and not with what is *felt* while the various actions are going on.

Brief reference has been made to the principles of the indestructibility of matter and the conservation of energy. These were adopted by men of science as the result of work in the fields of chemistry and physics. But we have every reason to believe that they hold good for living forms of every grade, human beings included.

Animals have an income and an outgo of matter and the two are strictly balanced unless the body is growing or wasting. They have, similarly, an income and an outgo of energy and the proof that here, too, nothing is lost or gained stands forth as one of the foremost achievements of our science in the last century. It would probably not have surprised a vitalist of the old school if it had been shown that an animal could develop energy independently of any external supply. This would have made it a *creator* or *generator* while we have come to regard it as a *transformer*.

Adaptation.—Biologists have made many efforts to define life. Their attempts have often been ingenious, though never entirely satisfying. Ignoring the possibility of consciousness in the organism observed (though necessarily recognizing its existence for the observer) a great thinker has said that life is "the continual adjustment of internal to external relations." It is certainly true that we judge by this standard when we attempt to decide whether a mass of matter is living or dead. If it shows no tendency to protect itself from the changing conditions which are brought to bear upon it we conclude that it is lifeless. This is what we should infer of a dog which lay in the road indifferent to the approach of an automobile. We look to see organisms adapting themselves to their circumstances so as to preserve their integrity in spite of many hostile forces. The study of *adaptation* is, accordingly, a large part of physiology.

The hard thing for the beginner is to regard this familiar adaptation as a mechanical process. He has always thought that the quest of food, the avoidance of enemies, the protection of the body against heat and cold were dictated by intelligence. Introspection encourages such a view by emphasizing the strength of the desire to prolong one's life. At the same time reflection convinces one that it is impossible to give the attention to all the serviceable reactions which are constantly taking place. Many of these usually pass unnoticed while in others

undue attention is more apt to result in a bungling than a superior performance. We have been led to the belief that they are the inevitable result of *structure* and not of present intelligence.

When we are overheated we perspire and the evaporation of water cools the skin and the fraction of the blood which is flowing through it. This is an adaptive change but it is obviously one which we can scarcely influence "by taking thought." It is like the adjustment which is made by the pendulum of a clock when the temperature rises. By an ingenious arrangement of different metals the tendency of the pendulum to lengthen, and so to be slowed, is offset. The preservation of the living organism through the summer day and the protection of the clock against the same disturbing agency are both examples of adjustment due to structural characters. It may be urged that the capacity of the clock to regulate its action under these conditions is owing to the wisdom and foresight of its maker and a reverent, parallel inference has often been drawn for the living organism.

The adaptive changes which an animal must execute to meet emergencies great and small are evidently varied from moment to moment and have no fixed order or succession. There are other life processes which are more constant and monotonous. These can generally be said to be related to *maintenance*. The mechanisms of breathing and the circulation, of alimentation and excretion, may be held to serve primarily for the maintenance of the organism as a whole, though the property of adaptability is frequently illustrated in connection with them. The adaptive mechanisms par excellence are the muscles and the sense-organs together with the central nervous system which correlates the former with the latter. In recent writings the sense-organs are often called the *receptors* while the muscles and the glands which are played upon through the central nervous system are named *effectors*.

The two names just used should explain themselves. A receptor is a structure which is exposed to external

influences—the eye to light, the nerve-endings in the skin to pressure, etc.—an effector is a structure capable of reaction in some measurable fashion. The possible responses of effectors include *movement* or its suspension, *secretion* or its suppression, and more rarely other phenomena such as the electric discharge of the torpedo or the flash of the fire-fly. Care was taken to include in the foregoing statement the negative types of reaction which should never be ignored. The word *inhibition* is used to mean a suspension of activity of effectors brought about by way of the nerves. We shall find it a more important element in our analysis than might be supposed.

Coördination.—A very little consideration of one of the higher animals convinces us that, while there are many parts or organs at work, the whole creature is more than an aggregate, it is an *individual*. To say this is to imply that in some way all the parts interact for the common good. We say that their activities are *coördinated*. Another term has come to be used to express the same fact: we say that the local actions are *integrated* by various means. To integrate, or confer integrity, is to bring the associated systems into such relationship that *wholeness*, unity, or individuality may characterize their union. A profound lesson may be apprehended in Kipling's story of "The Ship that Found Herself." The new freighter went out from a British port upon her first voyage. She encountered gales and head-seas which put her structure and equipment to the severest test. As she was racked in the storms every frame and plate, every bolt and rivet, raised a separate voice of complaint and recrimination against its mates. The discordant clamor lasted through the tedious trip. At length, on the fine morning when the ship glided into the harbor of New York, there was a moment of silence and then a great voice not heard before, the voice of the "Dimbula" herself, took the place of all the jarring tones. The ship was from that hour an organism and not merely an aggregation of parts.

As it does not call for much imagination to think of a ship or a locomotive as an integrated being, it should be still easier to recognize this essential fact in the world of living things. Someone has said that in the case of an animal "the whole is greater than the sum of its parts" and this is true in almost the same sense that a number made by combining three or four figures is greater than the sum of these digits. The interaction of parts makes possible results which could not be attained by the parts while isolated.

The Means of Coördination.—When one tries to decide how the evident condition of coördination or integration is secured, one is likely to think first of the nervous system as serving just this purpose. This is a correct idea, provided only that one does not fail to reserve a place for other agencies. When rapid changes in a certain region promptly follow changes somewhere else it can usually be inferred that the connecting link has been a nervous one. When, for example, a blow has fallen upon the head and the arm is thrown up to ward off another, the case is one of coördination through the medium of the nervous system. But the more gradual modifying of the activities of one organ in consequence of those of another has often a different basis. It may be due to the passage of chemical products from the place of their origin to some other locality where they can exert an influence. The importance of the chemical factors in the regulation of organic processes is more appreciated to-day than ever before and it is likely to have a still larger recognition in the future.

An illustration may be given. In the normal course of digestion the pancreas is found to enter upon the task of secreting its valuable juice at about the time when the stomach begins to transfer its contents to the small intestine. This is just when the pancreatic secretion is needed and the timeliness of the action makes us curious to know how it is brought about. The communication between the stomach and the pancreas has been found

to be less by means of the nervous system than by the passage of chemical substances through the circulation. Such chemical messengers, arising in certain parts of the body and perhaps affecting very remote parts, are commonly referred to as *hormones*. The very slow processes of growth and development are known to be greatly dependent upon the interchange of hormones.

Stimuli.—If objective life consists in the adjustment of internal to external conditions we shall do well to consider somewhat more fully than we have done the nature of the external factors. Any external condition which modifies the activities of a living organism may be called a stimulus. One naturally thinks of contacts, changes of temperature, chemical applications, and electric shocks. Light must not be left out of our list. A stimulus is best thought of as a *change* rather than a continued environmental state. A moment's thought will help one to realize that a *sustained* condition may favor the preservation of the plant or the animal, but it is the *shifting* of outward conditions which cause it to exhibit its capacity for reaction. Generally speaking, the more suddenly a change occurs the more marked is its effect upon living matter.

It would not be quite accurate to describe a stimulus as a force. A force may stimulate but so may the discontinuance of a force which has been operative for some time. Positive effects from negative factors are common enough. Silence may constitute a stimulus when it succeeds an accustomed sound. (Note, for instance, how one wakes at sea when the measured throb of the engine is interrupted.) We cannot deny that the reduction of the temperature of the skin is a source of stimulation, though this is a subtraction of energy from the tissues rather than a contribution.

CHAPTER II

PLANTS AND ANIMALS

While scientists believe implicitly in the conservation of energy they recognize also the principle which is sometimes spoken of as "the degradation of energy." According to this teaching, though the total quantity of energy in the universe cannot grow less it can be indefinitely dissipated. Thus our sun and the planets in its system are losing heat into the depths of measureless space. The amount of energy in the earth is not a constant, but a diminishing store. Since life as we now know it is dependent upon the maintenance of a certain temperature it cannot continue forever in a cooling environment.

Oxidation.—Our world has an internal store of heat, but this does not suffice to make its surface the abode of many forms of life save as it is supplemented by the rays of the sun. Wherever these fall daily from a considerable elevation above the horizon the temperature favors living organisms. But the service of the sun to the earth is not limited to the retaining of its surface at a desirable temperature level. The radiant energy is applied to the formation of what we call the *organic compounds* and while these exist it is held latent in them awaiting release.

A very crude classification of the substances we find in nature might be attempted by separating those which will burn from those that will not. Many things will burn at high temperatures which are not ordinarily thought of as combustible. For example, this is true of iron. If we restrict ourselves to the consideration of those things which we regard as fuels and which burn easily we shall be struck with the fact that they are products of past life,

in other words, they are organic in character. Wood, animal grease, vegetable oils, alcohol—these have but recently come from the sphere of living organisms. Coal, petroleum, and natural gas have arisen in connection with pre-historic life. We say of such materials that they are energetic or that they have distinct fuel-values.

The burning of fuels is a chemical process in which oxygen, usually supplied from the atmosphere, unites with their principal elements. Two of these elements, carbon and hydrogen, have particularly to be considered. When oxygen has united with carbon to the full extent that it will do so a gaseous product, carbon dioxid, is formed. This is also known as carbonic acid gas; it is familiar in the bubbles of soda water and it is the chief gas going up the chimney from a coal fire. When oxygen combines with hydrogen, water is formed and much more water arises from combustion than is commonly realized. In the flame of a candle oxygen is uniting with the carbon and hydrogen of the wax to produce carbon dioxid and water vapor. The ascending column of hot gases above the flame is composed very largely of these two compounds.

The generation of carbon dioxid and water by the literal burning of organic substances is not the only mode of their formation. Similar materials are constantly undergoing the same resolution in a more gradual way and without the accompaniment of flame and smoke. If we were to add "without heat" we should be wrong for it has been shown that just as much heat is evolved in the slowest as in the quickest oxidation of a given compound. Of course the heat production will be much less obvious if it is extended over a long time.

Physiological Oxidation.—The most interesting cases of oxidation of the more gradual type are those which go on under the influence of living matter and, indeed, constitute the most conspicuous part of its activity. Where there is life there will usually be perceptible oxidation. In the plant, as in the candle, organic matter is continually being degraded and again, carbon dioxid and water

are the major products set free. This may be said with equal truth of the animal and it may be pointed out that if the candle is an old-fashioned one, made of tallow, the fuel is the same that might have been used by the animal if its life had not been cut short.

When we deliberately cause fuels to burn, our object is usually to make some use of the energy which has been latent in them. We light the candle or the lamp that it may give us light. Fires are maintained to warm our houses, to bring about desirable changes in our food, or to keep machinery in motion. In every case the object is secured through the release of stored energy. It has been potential before and it now becomes kinetic or active. The service of oxidation to the animal is not essentially different. It is the source of animal heat and muscular power. It is hard for the elementary student to grasp the truth that decomposition is not disaster, but a necessary condition of living. It is only by expenditure, by the sacrifice of resources, that the organism can react and prove itself alive. The stores of the body are like money, useful not in themselves, but because of the results obtained in exchange for them.

If it were possible to suspend oxidation in the body of one of the higher animals it might be thought that it would remain motionless and cold but perfectly preserved for an indefinite time. Such a suspension of animation is unknown among higher forms; in them the restriction of oxygen supply perverts the life processes before it stops them and the result is the poisoning which we call asphyxia. Lower down in the scale we find such modifications of living matter as the seeds of plants, the spores of bacteria, and the encysted forms of certain aquatic animals which do represent, approximately at least, an arrest of respiration, and so of activity, which may be continued for a long while. A German writer has compared the state of such forms with that of a clock which is wound up but not going. There is the capacity for action but the mechanism remains under restraint.

Photosynthesis.—If the activities of living things all depend upon the oxidation of organic matter, how is the supply kept up? This is one of the great questions which biologists have been called upon to answer and they have been able to throw much light upon it. It has already been hinted that the energy of the sun enters into our reckoning. It is this energy which is applied to the reconstruction of fuels from the simple products of their decomposition. A work like this is manifestly the reverse, in a chemical sense, of oxidation and can be spoken of as *reduction*. It is, at the same time a *synthesis* and, since it occurs under the driving power of radiant energy, a *photosynthesis*.

Photosynthesis is accomplished chiefly by the higher, and pigmented plants. To say green plants would be nearly but not wholly correct. Every green leaf upon which the rays of the sun are falling is capable of making starch and other energetic compounds from the carbon dioxid and water vapor which are obtainable from the air. Since it is the reversal of combustion or oxidation it follows that when it is proceeding oxygen must be set free. It is interesting to recall the occasion upon which this important fact was first demonstrated. Joseph Priestley, an English scholar whose life story is peculiarly absorbing, prepared oxygen gas and observed its relation to combustion in 1774. He found that in a confined volume of air only a limited quantity of inflammable matter could be burned. But he soon made the momentous discovery that the power to support combustion could be restored to the exhausted air in a jar by allowing a green plant to grow inside it.

It is owing to the existence of colored plants that the composition of the atmosphere changes but very slightly from century to century. They abstract from it the carbon dioxid which has come from all the fires in the world, from all animal life, and from the vegetable kingdom too, for photosynthesis does not take the place of respiration in plants; it is a process which *accompanies*

respiration and goes on only under favoring conditions. At night all living things are consuming oxygen and giving forth carbon dioxid. The same reactions occur by day but the constructive activities of the higher plants are then so remarkable that we are prone to forget the undercurrent which is still setting in the opposite direction. Sometimes it is said that carbon dioxid and water are the principal foods of green plants, but it is more accurate to say that such plants have the power to make their foods from simple raw materials.

Attention should be called to the fact that light is not, on the whole, a factor that is favorable to life. It is highly destructive to the lower organisms and its value to man is indirect. It is helpful to him because it destroys some of his enemies, because it keeps up the food supply of the world, and because of its relation to his intellectual interests. Light is probably always detrimental rather than beneficial to defenseless living matter. This is to say that all transparent organisms are subject to injury through its influence. An important function of the pigment (chlorophyll) in those plants which profit by the light is probably to turn back from the leaves most of its searing rays and to admit only selected ones to the laboratories where the photosynthesis goes on. Our experiences with sunburn remind us that light may harm the human skin, while the development of tan suggests a protective reaction. It is not unreasonable to say that the chief reason why we are not more damaged by light is that we are too thick; it does not pierce to the seat of our vital processes.

Recognizing this, we find the synthetic application of light all the more remarkable and the scale on which the action proceeds is too vast for the imagination. The annual harvest of all the nations and the cut of timber give us an inkling of it. These immense returns from the vegetable world, we must remember, are produced only to a small extent from the soil but very largely from the air. This was the fact which surprised Van Helmont as

he reviewed a certain memorable experiment made about three hundred years ago. He had planted a young shoot of willow in a tub of earth and let it grow for five years. It had then increased in weight by about 160 pounds, though the soil had lost only a few ounces. So far as Van Helmont could judge the tree must have been made from the water that had been freely supplied. Water had indeed entered into its structure, but a larger addition was due to the unrecognized carbon dioxid of the atmosphere.

Interrelations of Plants and Animals.—It is now evident that a certain reciprocity exists between plants and animals. But this is true only when the plants considered are those with pigment; the uncolored varieties—fungi, etc.—are unable to make the fuels which they consume and are, therefore, like the animals in their dependence on the higher plants. Some forms exist which have intermediate powers. It is to be borne in mind, that, while the differences between typical animals and plants such as we naturally choose for comparison are striking enough, there are numerous species low down in the scale which are not surely to be assigned to one class or the other. Some of these have been claimed alternately by the botanists and the zoölogists.

Excluding all but the most highly developed types, let us consider how the proximity of plants and animals influences the economy of the two. A specific illustration may be suggested. Suppose that a snail is living in a hot-bed. The animal eats portions of the plants, living or dead. It returns carbon dioxid and water to the air and soil of the enclosure. The green leaves, transmuting the energy of light rays, can recover the fuel which the animal has dissipated. In thus compensating for the spendthrift proclivities of the animal the plants have returned to the air the oxygen which the animal appropriated. It is clear that the plants are necessary to the animal and that they must grow fast enough to make up

for the foraging of the snail or be exterminated. If they are destroyed the mollusc will be left to starve.

Is the animal necessary to the plants? The gardener will say that it is not and in the actual conditions of nature the snail can well be spared. There are other sources of carbon dioxid than the respiration of animals, and water is abundant enough in the world. The soil of the hotbed doubtless swarms with lowly and colorless plants which are oxidizing the surplus organic matter much as the animal does. Moreover, these organisms of the soil, mainly bacteria, affect usually the dead fragments detached from the green plants above and do not prey upon their living leaves as the animal does so ruthlessly.

Nitrogenous Compounds.—So far we have limited our discussion to the formation of fuels like starch or oils which yield no other products than carbon dioxid and water when they are completely oxidized. Such compounds are the chief source of energy for both plants and animals. But where life is manifested there will always be chemical compounds of another sort and, indeed, the bodies which are now to be discussed seem to be more intimately connected with life itself than the standard fuels we have been considering. The compounds in question are the *proteins*.

Proteins contain nitrogen. In a much smaller percentage they also contain sulphur. Phosphorus is present in some but not in the majority of the proteins. It will be plain that such compounds cannot be oxidized to carbon dioxid and water exclusively for the nitrogen and the sulphur must be represented in some form among the decomposition products. Neither can we have any formation of proteins without a supply of nitrogen and sulphur. At another time we may have occasion to emphasize the fact that the distinguishing character of the proteins is not so much the list of the elements which enter into them as the complex fashion in which these elements are combined. For the present we are concerned rather with the exchanges of these elements which occur in nature.

Plants synthesize proteins as well as starch. Little is known of the process in detail, but experience of the most practical kind shows that the most available supply of nitrogen for use in protein formation is afforded by the *nitrates* of the soil. These salts are received into the roots of plants and are transported in the sap. The sulphur required, a smaller quantity than the nitrogen, is secured in a similar way as dissolved sulphates. So phosphorus comes into the plant in the form of phosphates. These various salts we aim to furnish when we fertilize a plot of ground.

Animals take their proteins ready-made from plants. They do not, however, store the identical proteins which they have eaten. They digest them—a process of decomposition—and they synthesize a selected fraction of the products. But this is a much less radical reconstruction than that performed by the plants in manufacturing proteins from the simplest materials. The earlier writers used to make the sweeping assertion that animals are altogether destructive and can never carry on any constructive work. This is now seen to be untrue; destructive changes predominate in the sum of their life activities, but they often make complex compounds from simpler ones in special cases.

It may be asked how animals can synthesize chemical compounds of high fuel-value when they cannot apply to the task the energy of light. The answer is found in the fact that where the prevailing reactions are in the line of oxidation and attended by a release of abundant energy a portion of this energy may be employed to advance changes of the opposite order, those in which heat or other energy is absorbed. A man on first observing the hydraulic ram at work may be surprised to see water raised from the bottom of a ravine to a house high above the stream. But he can soon be convinced that the principle of the conservation of energy is not violated by this device; much more water is falling than rising all the time. The analogy is a close one; in the animal there is much

more oxidation than reduction, much more cleavage than synthesis, but some of the energy made available by the decomposition is turned to account to accomplish a certain amount of reconstruction.

Food.—It is now apparent that what we mean by a food is generally something which can be oxidized to yield energy for the support of the activities of the living state. In other words, most food is fuel. But this is not a sufficiently inclusive definition for the food of animals or plants. We wish to reckon water as a food and we cannot regard it as a fuel. There is the same difficulty with mineral salts. We ought to regard as food any supply that ministers to growth or repair as well as to the evolution of energy. Water is then a food because it makes good an unavoidable loss which the body suffers.

The proteins occupy an interesting position among foods because they are necessary for the construction of new living matter and at the same time they are available as a source of energy. The owner of a house might have a quantity of lumber brought to his premises with a view to having an addition built. If he then abandoned his plan he might saw up the boards and beams and use them for fuel. So we supply ourselves with proteins which are especially adapted to constructive uses and yet we consign most of them to our vital fires. The comparison is not wholly just; it conveys an impression of wastefulness and improvidence which we should scarcely hold to be valid in our own case or in that of animals, in general.

Ought we to class oxygen among foods? This has sometimes been done, but a good reason can be given for not admitting it to such rank. A food should either be a fuel or a means of repair. Now oxygen is an agent of destruction, and even though the decomposition is a highly characteristic part of life it is well to keep oxygen in a class by itself. We do not regard the draft which keeps the fire going in a stove as resembling the coal which we must also furnish. To think of the oxygen

rather than the fuel as the repository of energy waiting to be set free would be an unusual and confusing mental practice. We shall therefore place oxygen in contrast with food instead of extending the term food to include this other requisite of the living state.

Summary.—Animals and plants alike, though in unequal degree, are engaged while they live in turning the latent or potential energy of organic compounds (fuels) into heat. Mechanical work is done by them also and is a manifestation of the same great process. This oxidative release of energy which is coextensive with life we call respiration. It would soon terminate because of the exhaustion of the fuel supply of the world if a compensating process were not going on. This is photosynthesis, the manufacture of fresh stores of organic matter by the higher plants. It cannot occur unless there is a supply of energy to drive it, and the ultimate origin of this energy is in the sun.

It is to be borne in mind that it is not only animals for whose ravages the higher plants have to compensate. The lower plants are destructive in their general tendency. The fires which men build and those which run riot in the forests or over the prairies destroy immense quantities of fuel which can be recovered only by the pigmented plants and in the light. It seems an unequal struggle on the part of the leaves. Yet for ages the balance has been fairly maintained. It is a question whether human extravagance has now begun to disturb it. Many think that this is the case and pleas for the conservation of coal and the extension of woodland areas have become familiar. Whenever the power of falling water is substituted for that of steam we are sparing organic fuel, though we are still employing the energy of the sun.

The Work of Bacteria.—The statement has been made that colorless plants act more or less like animals as judged by the chief chemical effects which they produce. It has also been said that they destroy the dead remains

of the higher plants and turn them into forms of matter which can reënter the life cycle of the vegetable world. Similarly, the colorless plants are the agents of decay where animal remains are concerned. Especial attention should be given to the action of some of these colorless plants—the bacteria—upon the waste-products of animals.

Carbon dioxid and water, the major wastes of animal life, are set free in fit condition to be used at once in photosynthesis. This is not true of the nitrogenous excretions of animals. Take, for example, the compound *urea* which is the principal form in which nitrogen is eliminated by mammals. This is not directly valuable to the higher plants when it is dissolved in the soil about their roots. But there are bacteria which can transform *urea* into other substances beneficial to them. The result is not brought about by a single reaction but by stages, probably by three successive processes and three different kinds of organisms.

Urea is first changed to compounds of *ammonia*. These in their turn are oxidized to *nitrites*. The final step is the further oxidation of the *nitrites* to *nitrates*. The utility of the *nitrates* in protein synthesis as carried on by green plants has already been noted. A striking demonstration of it occurs in connection with well waters. These have been long in the earth and are rich in *nitrates* as compared with rain or surface waters. If well waters are pumped into open reservoirs and left standing in the sunlight they encourage the growth of green plants (*algæ*) to an extent which is most undesirable in a public supply. If reservoirs which are roofed over are provided for the storage of such waters no troublesome growth will develop.

The term *Cycle of Nitrogen* has been used to denote the endless process in course of which protein is built up by plants from simple materials and with the aid of the solar energy, to be destroyed by the respiratory activity of the plant itself, or of an animal, and then

to be further degraded, so far as its nitrogenous groupings are concerned, by the bacteria of the soil. No mention has been made in this discussion of the abounding atmospheric nitrogen. The free element does not arise in any great quantity from organic decompositions nor does it generally enter into the economy of living matter directly from the air. In a few cases, which are highly important, nitrogen *is* captured by bacteria and "fixed" by them as a part of their own substance.

CHAPTER III

CELLS AND THEIR ASSOCIATION

We can imagine a giant of enormous stature and a curious turn of mind who might walk about the earth looking down upon the buildings which men have made as we look at the pebbles in our path. For such a giant a brick house might appear as an object with uniformly red surfaces; the white lines of the mortar might easily be too fine for his vision. He could not observe the fact that the walls of the house are made of individual bricks. This might be revealed to the colossus if he were provided with a microscope of suitable proportions.

Man has had an experience not unlike that which has just been suggested. Through centuries of eager intellectual life he could not see that the green surface of a leaf is a mosaic of minute units. He could not resolve the substance of an animal body into its constituent parts. The modern microscope had to be perfected before this knowledge could be compassed. More than two hundred and fifty years ago there were drawings and descriptions of the appearance of parts of plants and animals under high magnification. Some of these were surprisingly accurate. But the lenses available in the seventeenth century were poor affairs which blurred and distorted the images which they formed. The investigator had to make the best of these faulty aids and, in addition, to ignore so far as he could the fringes of rainbow colors which bordered every object of his study. As Holmes has said, "he saw through a glass darkly."

Great improvements in lenses were made about the year 1830, and biologists hastened to employ the new instruments. A fruitful period of research and publica-

tion followed. Within a decade the scientific world had fairly grasped the conception which we know as the *Cell Theory*. What this is and what it implies must now be shown with some care. What do we mean when we speak of a cell?

It must be admitted at once that the word cell is not particularly appropriate in the sense in which it has come to be used. A cell is properly a walled space, as in the prison or the honeycomb. In biologic parlance a cell is a small parcel of living matter. It is easy to explain how the name began to be used. Dead and dry vegetable substance, like cork which was one of the first forms studied, has a structure which can be correctly described as cellular. There are myriads of microscopic spaces set apart by walls. The arrangement was pictured carefully by Robert Hooke about the year 1665. The cells seen by this early worker were actual cavities, but we have come to employ the term for the separate packets of organized material which occupied these cavities when the tissue was living and growing.

The microscope shows that bits of animal matter also consist of assembled units of about the same average size as those of plants. But the so-called cells in the animal are not commonly isolated by rigid and durable partitions. Between neighboring ones the intervals may be occupied by fluid, or partially taken up by fibers, or there may be more or less compact deposits, but in general one receives the impression from observation of animal cells that they are often in practical contact one with another and that it is curious that they do not run together. There is reason to suppose that the surface of each cell presents a film somewhat different in character from the interior; this is sometimes spoken of as the cell-membrane, but it is of extreme delicacy and not to be compared with the substantial walls which bound the cells of plants.

Cells vary widely in size. There are probably more which measure less than $\frac{1}{1000}$ inch in diameter than there

are which exceed this scale. The name *protoplasm* is given to the characteristic material of which cells are composed. In most cases there can be demonstrated in a cell an internal mass which seems denser than the rest. This is called the *nucleus*. When we recognize it we at once have need of a word to describe the part of the cell external to the nucleus; the word chosen is *cytoplasm*. We are in the habit of speaking of the cell as a small mass of living matter, but we are compelled to admit when questioned that we do not know what proportion of the whole is truly alive. This is a stimulating but rather hopeless line of inquiry.

When cells from different parts of the body are compared we can recognize that some show special adapta-

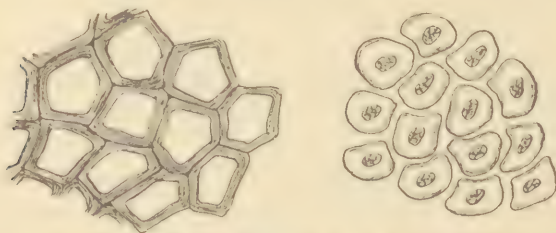


FIG. 1.—To contrast the empty "cells" of a dry, woody tissue, enclosed by substantial walls, with the "cells" of a soft, animal tissue which are separate parcels of living matter. They are related to the other somewhat as casts to their moulds.

tion to particular uses while others are obviously of a more primitive type. Cells that can be regarded as primitive suggest to one that the standard form is the sphere. Yet this form is seldom perfectly realized, chiefly because cells which are pressed together naturally come to have flattened surfaces at places of contact. Thus they are like grapes that have been packed too tightly. We ought to think of cells as of a very soft consistency. The structural strength of the body as a whole is gained through the development in it of deposits and fibers which are not cellular but *intercellular* in nature.

Tissues.—Before cells were recognized as characteristic units, into which living matter can be resolved, anatomo-

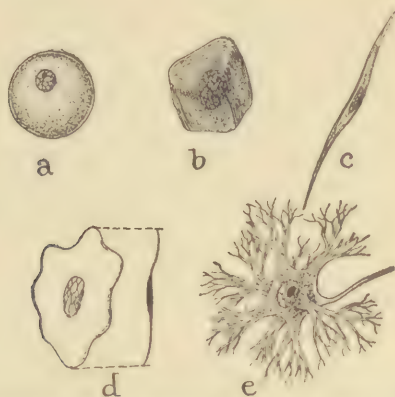


FIG. 2.—Drawings like the above are almost always made from tissues which have been prepared and colored by special means to make clear, minute features: *a* represents an ovum or egg-cell, the typical cell may be assumed to tend toward this spheric form; *b* is a cell from a compact tissue, to show how mutual pressure produces a faceted or polyhedral form; *c* is a contractile element such as occurs in the walls of the alimentary canal, it illustrates an elongated cell; *d* is an epithelial or lining cell of the order found on the inner surface of blood-vessels; this is an example of extreme flattening; *e*, from the nervous system, exhibits the possibility of a branching development.

mists knew that the bodies of animals were composed of various types of material, the *tissues*. Thus we say that bone, muscle, skin, the substance of the nervous system, and blood are tissues. In the light of the cell theory we are inclined to think of a tissue as a collection of similar cells. This is not wholly satisfactory, for the character of a given tissue is often more dependent on the nature and amount of the intercellular matter mentioned above than on the peculiarities of the cells. Therefore, it is best to regard a tissue as consisting of associated cells *and* intercellular accumulations. In some cases, as in the skin, the intercellular deposit is slight; at the other extreme we have cartilage and bone

where the cells form but a very small fraction of the total mass.

It was suggested a moment ago that blood is a tissue. This may not be a familiar idea nor one that is universally acceptable. But it will be noted that blood conforms with the terms of our definition. It contains cells of standard kinds with intervening material which in this instance is a liquid. There is more or less intercellular fluid in almost any variety of tissue.

Four conspicuous orders of tissues may be set apart. They are (1) the epithelial, (2) the connective, (3) the contractile, and (4) the nervous. Those of the first class (*epithelial tissues*) are the surface tissues, the coverings

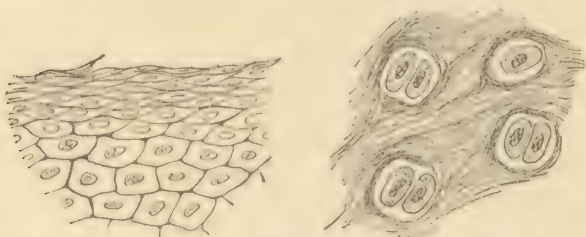


FIG. 3.—To emphasize the difference between an epithelial tissue (at the left) in which the cells are closely packed and a form of connective tissue (cartilage) consisting mainly of an intercellular deposit.

and linings of the organs. An epithelium may consist of a single layer of cells or of more than one. The thinnest developments of this character are exemplified in the partitions between the air and the blood in the lungs. In calloused portions of the skin the number of layers of cells is large and those on the outer surface are lifeless, flattened, and dry. Epithelial cells, as a rule, keep growing and subdividing throughout life to make good the loss by degeneration and detachment that is constantly going on.

Connective tissues have the general function which the name indicates. Bone is an example and what the skeleton does for the body as a whole is done for each

organ by a supporting web of material belonging to this class. Under this head we may mention the tendons which join muscles with bones and the ligaments which unite the bones at the movable joints. As already suggested the cells of connective tissue are not much in evidence. It is the intercellular substances, in the form of fibers, concrete, or mineralized deposits that fit such tissues to serve their purpose.

Contractile tissues are those which produce movement by an energetic change of form. They are able to do this because they can derive power from certain chemical compounds which they decompose. The problems of muscle physiology confront us here. It is well to point out that the tissues which display the property of contractility are heat-producing tissues at the same time.

The *nervous tissues* are in many respects the most remarkable and baffling of all. An attempt to deal with them will be made later on; it may be said at this point that their chief service is to maintain the relationship between the sense-organs and the contractile tissues. In other words their function is that of coördination. This seems a very inadequate statement when we consider the mysterious correlation between the brain and our consciousness, yet we shall find that most of the strict physiology of the nervous system can be harmonized with it.

The contractile and the nervous tissues have been called the "master tissues" of the body. It is quite clear that they are more essentially living and active than the others. One can imagine non-living substitutes for bones and tendons—and, in fact, such are sometimes used—but one cannot imagine any lifeless contrivance that could replace a muscle or a section of the nervous system. As to the epithelial tissues, it might be supposed that these would be found purely passive but this turns out not to be the case. It is through the epithelial expanses that transfers of food

and waste go on between organisms and their environment. The processes involved, secretion and absorption, cannot be reproduced with non-living membranes.

Free-living Cells.—A cell from the body of one of the higher animals cannot continue to live when separated from its fellows. But nature abounds in organisms which are single cells. These may be reckoned according to their nutritional requirements in different instances as either plants or animals. So the bacteria are considered to be plants because they can live on classes of supplies which are simpler in their constitution than those which animal life ordinarily demands. The *Infusoria* of stagnant water, which are seen to devour organic matter and whose lively habits constantly remind us of the higher forms, are regarded as animals. But, as has been stated before, the distinctions between plants and animals have only a limited value when applied to the lower orders of life.

A free-living cell of the animal type has probably all the activities which have been described in the preceding chapter as characteristic of animals in general. That is to say, it appropriates supplies of complex matter, using some to promote its own growth but more to furnish the energy for movement and heat production. This energy it makes available by a respiratory process in which oxygen is consumed and simple end-products formed. Movement in the independent cell, as in the larger organisms, is the expression of contraction. Some explanation of this term is desirable.

Contraction, as the biologist understands it, does not mean diminution of volume. It is thus different from contraction in the physical sense. When the mercury in the thermometer tube contracts under the influence of cold there is an actual reduction of the space which the metal occupies. When a muscle contracts it can be shown that the volume is unchanged; there has been a shortening in one dimension but a compensating thickening in others. Changes of form which are observed in

single cells are doubtless of this kind, save in those cases in which water enters or leaves. This exceptional possibility we shall not be obliged to consider in the present treatment of the subject.

Many of the facts of life which we assume for free-living cells can hardly be demonstrated but are rather inferred from what we know of higher organisms. The



FIG. 4.—The purpose of this diagram is to assist the student in gaining notions of scale. The large circle stands for the cross-section of a fine hair. Its diameter is supposed to be $\frac{1}{500}$ inch. Within it (*bl*) is a red blood corpuscle, $\frac{1}{3200}$ inch across. The budding yeast-cell (*y*) is of a similar order of magnitude. Bacteria (*bact.*) are a good deal smaller.

production of heat, for example, is something we can scarcely hope to measure when only one cell is concerned, but we cannot doubt that it is going on because we know that it is evident when sufficiently large numbers of active cells are massed. The phenomena we can most easily make out in a study of solitary cells are the taking of food, motion, and reproduction. A word may be said about the last-named manifestation of life.

Cell Reproduction.—A cell which is well nourished and otherwise in a favorable condition soon attains to a size which marks the limit for its growth. Instead of increasing further in bulk it cleaves into two parts which are complete and living cells. The cells of the new

generation are at first undersized, but these in their turn grow to the standard of the species. It is curious to reflect that there is a kind of physical immortality belonging to the one-celled organisms. Cell-division is obviously not death. Many members of the family are killed by accidental means, but they do not seem fated to grow old and perish from any intrinsic property of their own. The cell which is living to-day has descended from a line of ancestral cells *no one of which has ever died*.

This assertion may be made with reference to the cells of higher plants and animals as well as to those which live alone. No cell that is living to-day has ever lost a direct ancestor by death. Let us see in what sense this is true. Take, for example, a cell in the human skin. Its neighbors at the surface are rapidly dying, shriveling, and being cast off. This will be its own probable fate. But, if we look backward instead of forward, we recognize that this selected cell was formed a short time ago by the cleavage of a preëxisting cell. The companion formed at the same time may have perished but the fact remains that the ancestor did not die. The same may be said of the parent cell in the previous generation.

As we trace the succession backward our attention becomes fixed at last upon some cell in the embryo and eventually upon the single cell, the fertilized egg or ovum, from which all the countless host of cells in the mature body are descended. This lived before the individual whom we have chosen to picture. "Omnis cellula e cellula," said Virchow in the last century. "Omne vivum ex ovo," Harvey had written two hundred years before. Either of these famous sayings will serve to bring home to us the fascinating thought of the uninterrupted living bonds which unite all forms of the present with the most distant past. In retrospect these threads of life seem endless, yet any one of them may terminate at any moment.

When we think of our ancestors who have died—perhaps fourteen of them in a hundred years—we must be impressed by the disproportion between the mass of their tissues which perished and the infinitesimal survival in ourselves of what they transmitted to us. Someone has said that the body is like a great lantern, serving primarily to save the tiny, trembling flame of the germinal life from being extinguished. It is a lantern which wears out and only the flame can be saved to burn for a time in a fresh protective shell. One contrast between single-celled and many-celled forms of life will now be clear: in the former the whole substance of one generation may live to constitute the next, in the latter the accumulated cells of the body die and under the most favorable conditions leave but the minutest part to represent the stock.

Another difference between the unicellular and the more highly developed organisms is associated with sex. A single bacterium may give rise to two, and these to four descendants, and so on. A solitary member of any of the more advanced types must mate with another of opposite sex if the species is to be reproduced. The fertilized ovum, before mentioned, which develops into the embryo and so into the mature individual may be called one cell, but it is more truly a composite of two half-cells, one furnished by the male and one by the female. Thus the animal of the higher sort has two parents, four grandparents, eight ancestors in the next generation, the numbers soon becoming enormous as we reckon backward. The bacterium, on the other hand, has but one ancestor in a generation.

The case of the one-celled animal forms is not so simple as may have appeared from the unqualified statements that have been made. Close observation of these orders of life has shown that, while the multiplication of cells by cleavage is the common process among them, in many instances the fusion of two cells into one (*conjugation*) is a possibility. When it takes place there is

reason to believe that a more vigorous and enduring organism is produced. It is a means of rejuvenation. Conjugation of free-living cells seems a prophecy of sex as realized in the higher varieties of plants and animals. In these we know that the union of the two germ-cells gives rise to an organism which we call young, meaning that it has powers of growth and development which the parents have largely lost.

We ought now to compare somewhat fully the situation of a cell that exists alone and one which acts as a member of the great community making up the body of one of the larger animals. In the first place, a direct consequence of the size of such a body is that the great majority of the cells are submerged and surrounded by their fellows instead of maintaining immediate relations with the outside world. Special provision must be made for bringing food to such cells and relieving them of waste. These purposes are served in the higher animals by liquid media, the blood and the lymph.

The blood is confined to a system of vessels in which it moves steadily in one direction. Only those cells which line the vessels are actually bathed by the blood. All other cells—and this means the vast majority—are removed from direct contact with the blood but have around and between them the second fluid, the lymph. From this they draw nutriment and oxygen; to it they discharge carbon dioxid and other products of their activity. The lymph adjacent to any one cell is a very limited quantity and if there were no provision for its renewal its usefulness would soon be at an end. But the blood is flowing close by in capillaries whose thin walls scarcely impede the passage of dissolved gases and other materials between the blood and the lymph. By a continuous exchange between the two fluids the lymph is relieved of cell waste and held to a standard composition as regards oxygen and food.

One of the striking facts we note when we compare free-living and associated cells is expressed by the term

“division of labor” which is used with reference to the latter. The cells are evidently of different orders and specially adapted to particular functions. Those of muscle are eminently contractile. Those of the nervous tissues have most highly developed the property of conduction. Some, as in the skin, have it their chief duty to provide hosts of descendants whose dead remains may form a protective covering. The specific service of the cells in the connective tissues is to elaborate inter-cellular deposits.

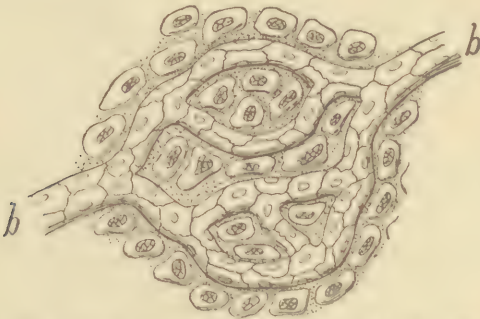


FIG. 5.—To suggest the confinement of the blood within definite vessels (*bb*). The lymph occupies the dotted region between these blood-vessels and the tissue-cells.

Along with specialization such as has been illustrated the cells lose some of the primitive endowments. A cell of muscle or of the nervous system cannot feed upon all sorts of food particles like the roving infusorium. It is limited to the use of dissolved foods which must be of a few standard types. The power of movement is not preserved in the majority of cells in the higher animals. It is the peculiar property of the muscular tissues. When the body is in motion it is these elements which are at work and all the rest are moved by them. The result of physiologic division of labor, combined with the removal of most cells from direct relations with the outside world, is the absolute dependence of each cell

upon the contributions of others for its continued existence.

One of the capacities which may be lost in connection with specialization of structure and function on the part of cells is that of reproduction. We have seen that this is retained by epithelial units; its persistence in the hair and the nails is most remarkable. But it is not retained by the most conspicuous kind of muscle in the body. The enlargement of a muscle in consequence of exercise is due to increased size of the individual units and not to their multiplication. So, too, in the nervous system: the wonderful advances in the working of the brain from infancy to maturity are not assisted by the addition of a single cell to the number originally present but only by the organization of this collection.

Elements of Anatomy

Our natural interest will center in the physiology of man, and before we go farther the outlines of human anatomy may be very briefly suggested. The skin, which forms the surface of the body, is an epithelium of many layers. Beneath it there is loose connective tissue, more or less rich in fat. Deeper still we find the muscles. The bones, articulated as the skeleton, give support and fixed proportions to the whole. In various places between the skin and the bones we find the white nerves and the large blood-vessels. These are of two classes, arteries which carry blood away from the heart and veins which conduct blood back toward that organ. The arteries generally lie at some depth below the surface while veins are situated at all depths, the superficial ones being visible through the skin.

The Body Cavities.—The features which have been mentioned are all that need be included in a simple description of what is to be seen in dissecting an arm or a leg, but the case is different with the head or the trunk. In these are what we speak of as *cavities*; the

use of the word needs to be carefully defined. The student is apt to imagine that the so-called body cavities contain more or less vacant space. This is not the actual condition. They are only potential cavities which become real ones when their contents have been removed. In life they are completely filled by the organs, plus a small quantity of fluid.

In the head the principal cavity is that which we call the cranial one, the space which accommodates the brain. It is bounded by bones pierced here and there by small openings for the nerves and at one place by the larger orifice through which the spinal cord descends. This last-mentioned opening is at the base of the skull and leads to a tunnel made by the successive bony arches of the vertebræ. In the trunk we distinguish two main cavities, that of the thorax within the sweep of the ribs and that of the abdomen below. The partition between them is the diaphragm, a sheet composed partly of muscular and partly of connective tissue which has the form of a tolerably high dome and therefore subtracts much space from the apparent size of the thorax and adds it to the abdomen. Below the abdomen and within the circle of the hip-girdle is the small pelvic cavity.

A striking fact about the body cavities is that the organs which they contain are not attached to the encompassing walls save at a few places. For the most part the surfaces of the organs bear upon surfaces of the body walls but do not adhere to them. The arrangement permits a certain amount of gliding of one upon the other. There cannot normally be a separation between them since this would involve the creation of a vacuum. The relation between an organ and the opposing body wall is much like that between two plates of glass which have been moistened and laid together. One will slide freely upon the other, but it requires great force to pull them apart until air begins to penetrate between them.

The *thorax* is divided vertically into right and left

sections by a development of connective tissue called the mediastinum. In this is suspended the heart surrounded by a sac, the pericardium. On either side of the mediastinum is a typic cavity, lined with a smooth, moist membrane which is in contact with another

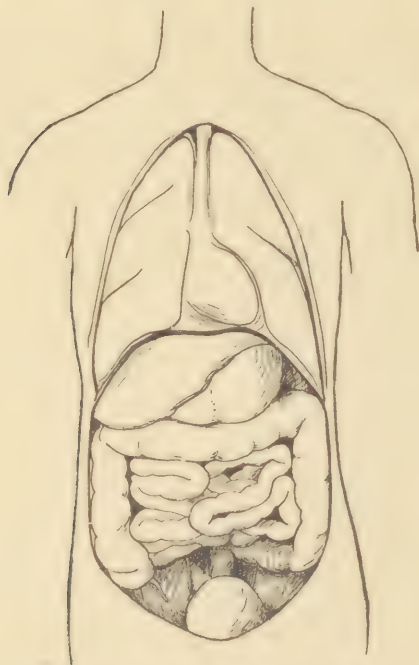


FIG. 6.—Suggesting the thoracic and abdominal cavities parted by the diaphragm. The abdominal viscera are drawn upward, creating a space above the bladder where none normally exists.

membrane of the same nature covering the lung. The linings of these two cavities and the coverings of the two lungs are spoken of as the layers of the pleura.

The *abdominal cavity* is lined by a membrane similar to the pleura and called the peritoneum. The principal organs contained in the abdomen are those belonging

to the digestive system. The central feature of this system is the alimentary canal which, as a matter of fact, is not strictly confined to the abdominal cavity since it begins at the mouth, extends through the thorax, and at its lower termination traverses the pelvis to open at the anus. Nevertheless, the great part of the digestive tract is in the abdomen. The liver and the pancreas are appended to the canal and the spleen is associated with it though perhaps less directly. The kidneys are exposed to view when the organs of digestion are removed from the abdominal cavity; they lie behind the peritoneum and are best thought of as belonging to the back rather than to the abdomen.

In the pelvis there are found the terminal portion of the alimentary canal, as already noted, the urinary bladder, and the reproductive organs. The peritoneum intervenes between the pelvic cavity and that of the abdomen above. Details will be added as we discuss the particular organs which have merely been mentioned at this place.

Anatomical Terms.—It will be well to define here a few terms of anatomy which must often be used. Right and left have their ordinary meaning. Dorsal signifies toward the back and ventral is its opposite (venter, the belly). There is an unfortunate confusion in regard to the employment of anterior and posterior. They have been much used as though equivalent to ventral and dorsal respectively. But another usage which appears more desirable is to define anterior as toward the head, posterior being the reverse. Anterior is then the same as superior, posterior is synonymous with inferior. If we adhere to the practices outlined we shall have no difficulty in comparing the structural relations in the lower animals with those in man. Such difficulty is experienced where the other significance is given to anterior and posterior; as an animal walks the anterior parts precede the posterior but in the erect position the ventral precedes the dorsal.

CHAPTER IV

CONTRACTILE TISSUES

It is a peculiar fact about physiology that very different orders of presentation have commended themselves to different writers and have been used with success. Whatever one chooses to place first, one is likely soon to wish that the student were in possession of some other part of the subject to serve him as a background. But there is much to be said in favor of the introduction early in a book of the physiology of movement. We have to reckon with it in all the remaining sections of our survey. So in the present instance we shall take up the question of motion at this time.

It has been said previously that most of the movements executed by animal cells are the expression of contraction as that term is understood by the biologist. Such movements may be carried out by single cells or by tissues composed of cells whose action is concerted. We could know nothing about the behavior of single cells if we had not the assistance of the microscope. Thanks to that instrument we have found out that the two exhibitions of contractility which are most common among one-celled animal forms are to be seen also in the higher organisms. These are, respectively, *ameboid* and *ciliary* movement.

Ameboid Movement.—This manifestation of the contractile property takes its name from a single-celled aquatic animal, the ameba. It is one of the simplest types conceivable, a minute mass of jelly-like substance with a nucleus which confirms its right to rank as a cell. It is usually colorless and transparent except for numerous granules within. Its movement consists in the most

irregular changes in outline, the border at certain places drawing in toward the center and at others pushing out in blunt protrusions. When one first watches an ameba the impression is that extension rather than contraction is the characteristic of the movement displayed. Closer study shows that the positive phase is really contraction.

When a process runs out briskly while the remainder of the cell appears to be at rest the natural inference is that the process itself is active. But the fact seems rather to be that the main mass of the cell is exerting a



FIG. 7.—Ameba. (From Calkins' "Biology," Courtesy of Henry Holt & Co. Publishers.)

pressure which drives or spurts out the process. The reader may have seen small rubber balls with faces painted on them and tongues of thin rubber which dart out when the balls are squeezed. The protrusion in this case is probably the same in principle as that which obtains with the ameba; pressure in one part results in extension in another, the moving part being passive and the real source of the power not being apparent.

Uniform conditions of contraction in a cell like the ameba tend to bring it into a spheric form for this is

the shape which presents the minimum surface. Strong irritation of the ameba causes it to assume this form. It is in fact a general law of contraction that the elements acting approach a spheric form as a geometric limit. When the ameba begins to put out processes and resume movement after a period of intense contraction it is to be supposed that the pressure directed inward at certain points has diminished; thereupon the pressure at other places is no longer counterbalanced and risings of the surface occur in the areas of lowered resistance.

Ameboid movement is exemplified in the bodies of the higher animals, including our own, by cells found in the blood and called *leucocytes*. The word means "white cells" and has been applied because these cells are contrasted with the much more numerous red corpuscles of the blood by their lack of pigment. Under favorable conditions many of them change their forms in a manner which is highly suggestive of the free-living amebæ and it was maintained at one time that the leucocytes were parasites rather than normal body cells. It is now established that they are both normal and valuable in the organism.

Cells which have the ameboid character have usually the power to enclose all manner of foreign particles with which they come into contact. It is by such means that the aquatic amebæ secure food. A similar capacity is observed in the case of the leucocytes; they also submerge in their own substance various small bodies which, in favorable instances, may be digested and entirely obliterated. This action has a peculiar importance because bacteria are frequently devoured in this way and so we count the leucocytes as defenders of the organism against mischief-making invaders. The process in course of which bacteria are engulfed and destroyed is called *phagocytosis*. Around a threatened spot, such as a wound containing dirt, leucocytes in vast numbers are massed in the tissues. The student marvels that they should be gathered so surely at the very place where their

presence is required, but we do not have to assume anything like intelligence on the part of these cells to account for the facts. We are probably to suppose that conditions arise in such regions which arrest the leucocytes brought into the area by the flowing blood.

A large proportion of the leucocytes which are thus concerned in contending with an infection are found not to be inside but outside the blood-vessels. How they made their escape is a natural question. Direct observation with the microscope of inflamed areas has shown that the leucocytes slip out of the capillaries by

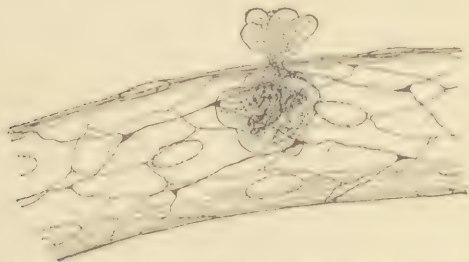


FIG. 8.—A leucocyte is escaping through a cleft between adjoining cells of a capillary wall. Such a passage of the ameboid corpuscles from within the vessels to the tissue spaces outside is called *diapedesis*.

exercising their power of ameboid movement. The walls of these, the most slender of the blood-vessels, are exquisitely thin. The cells which compose them are flattened to an extreme degree and where they are joined along their edges there seems to be little resistance to force applied to push them apart. These joints are forced by the leucocytes which gradually transfer themselves from the interior to the outside by flowing through the minute gaps thus opened. While the operation is in progress the leucocyte which is being watched consists of two principal masses united by a strand that runs through the crack. One of the masses

is increasing and the other diminishing as the transfer goes on.

Ciliated Cells.—Many one-celled animals have upon their surface a sort of nap or pile which is made up of very fine contractile extensions of the cell substance. The suggestion is of bristles set in a brush. Every individual "bristle"—the term inevitably suggests something a great deal coarser than the reality—is swinging back and forth. A balanced, pendular movement of this kind would slightly stir the water nearest to the infusorium but could not materially affect the situation. But the movement of the cilia, as these tiny processes are called, is not balanced and pendular. It has a most curious unsymmetric character. The stroke made in one direction is sharp and decisive, the recovery is slower and more gentle. One is reminded of the handling of a whip or of an oar; in either of these cases a forcible stroke in one direction is followed by a less energetic return.

A ciliated infusorium when not attached to any anchorage is propelled here and there by its waving cilia. The action is like that of the many oars of a Roman galley. If, however, the animalecule is fixed in its position the movement brought about by the cilia is not in the cell but in the adjacent water. Currents are maintained which are in many cases so directed as to bring food particles within reach of the infusorium. The same currents must assist in ministering to respiration by sweeping away water which has received carbon dioxid and replacing it with a fresh portion containing available oxygen.

The ciliated cells which are found in the higher animals are usually arranged in mosaic fashion to form epithelial surfaces. The cilia are upon the exposed aspect and their beating is effective in a direction that is the same for all the assembled cells. Cilia in such localities are undoubtedly overlaid by a film of moisture or mucus and this is kept travelling by their rapidly repeated strokes.

Any small bodies which adhere to such surfaces are accordingly carried along with the creeping film. Progress is slow, it may be only $\frac{1}{2}$ inch in a minute, but it is definite and sometimes a matter of importance.

The effects of ciliary movement may be seen when the esophagus of a frog is laid open and bits of chalk are sprinkled upon the lining membrane. These will be taken steadily toward the stomach. The cilia continue to be active long after the death of most other tissues. This demonstration upon the frog is so commonly made that students need to be told that there are

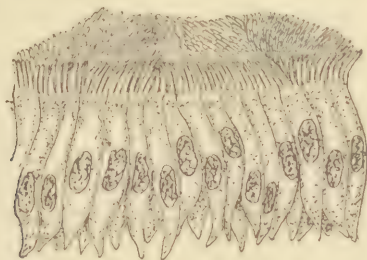


FIG. 9.—A portion of ciliated epithelium as it might be seen under the microscope if that instrument could give a perspective effect. At the front the cells are sectioned, while above and receding we have their ciliated surface. There is a suggestion of coördinated movement in that the cilia in great numbers have a parallel direction but it is not supposed that the order of the actual performance can be presented to the eye.

no cilia upon the lining of the esophagus in the mammal. The cleansing of this passage which is accomplished by the cilia in the frog is effected in ourselves by swallowing saliva or water.

Human beings do have cilia in the respiratory tract. The lining of the nasal cavities is equipped in this way and so is that of the lower passages leading from the larynx to the depths of the lungs. Particles of dust, including many germs, which settle upon these surfaces are not allowed to remain where they fall but are at once put in motion. In the bronchial tubes the move-

ment is from below upward toward the throat; there is some doubt as to the course of the ciliary currents in the nose. Dust which might accumulate in the lungs with serious results is continually cleared away and gathered temporarily about the root of the tongue. Eventually it is swallowed. We may not find the notion agreeable, but it is a fact that all the people in a dusty place are acting as vacuum cleaners, freeing the air of a part of the suspended material and depositing it in their own stomachs. Note that the direction of the currents in the trachea is upward while in the frog's esophagus it is downward.

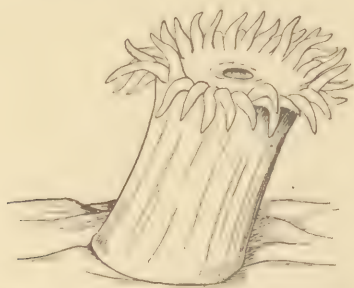


FIG. 10.—The sea anemone. See text.

The microscopic air-sacs to which the finest bronchial tubes lead are without cilia. There is no provision for the removal to the throat of dust which runs the gauntlet without being arrested and arrives in these terminal chambers. Such dust will remain in the tissue of the lungs and may discolor those organs to a degree which varies with the environment of the individual. Coal miners have their lungs greatly stained with the dust they have inhaled, but the portion which is retained must be an exceedingly small fraction of the total which they have breathed.

Do cilia ever reverse the direction of their effective stroke? The question cannot be answered surely for the mammal, but a reversal has been observed in a

lowlier type of organism, the sea anemone. This animal is found adhering to the bottom of pools of salt water along rocky coasts. Its appearance is that of a vegetable rather than an animal type; it is a short cylinder crowned with a circle of tentacles. Inside the ring of tentacles there is a flat surface surrounding a mouth. The zone between the tentacles and the mouth is ciliated. If a grain of sand is dropped upon this area it is seen to move away from the oral opening. Thus the cilia are ordinarily so acting as to protect the animal against the tendency to become filled with useless débris. This is the more important because the simple digestive cavity of the sea anemone has no outlet.

If the experimenter places a morsel of meat instead of a sand grain upon the surface which he is observing the result is very curious. The bit of meat at first moves a little away from the mouth. Then it comes to a stand-still and in a moment more it is journeying toward the mouth into which it presently falls. The chemical composition of the edible particle has been such as to modify the action of the ciliated cells. The mechanism of this reversal might be pictured in various ways, but such attempts would be purely speculative and we will content ourselves with the mere statement of the facts.

Muscular Tissue.—Ameboid cells are found singly and the activities of one are independent of those of another. Ciliated cells, as seen in the higher forms, are in a fixed association. The evident movements of such forms are produced by the coördinated working of cells organized into those tissues which we speak of as muscular. Mammalian muscle is of three principal varieties. The kind which seems distinctly the most primitive is that which we call *plain* or *smooth* muscular tissue. This is found chiefly in the internal organs and it is sometimes termed *visceral* muscle because of this fact. A unique sort of muscle is found in the walls of the heart

and is consequently named *cardiac*. The third order, which is responsible for the movements of the limbs, for breathing, balancing, facial expression, speech, etc., is best called *skeletal*.

Smooth Muscle.—The properties of cardiac muscle may well be taken up in connection with the physiology of the heart. Those of skeletal muscle will be discussed in the next chapter. It will be desirable at this place to say something of smooth muscle. We have just said that this kind of contractile tissue is most conspicuous in the internal organs. For example, it is responsible for the movements of the alimentary canal, the contractions of the gall-bladder, the urinary bladder, and the uterus. But is not restricted to these localities.

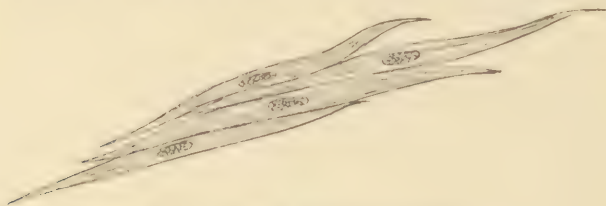


FIG. 11.—Cells of smooth muscle.

It occurs in the blood-vessels, the bronchial tubes, the eye, and, sparsely distributed, in the skin.

The cells of smooth muscle are nowhere massed to form layers of any great thickness. They are generally arranged to form sheets adapted to enter into the structure of hollow organs or vessels. The individual cells are slender and elongated, tapering to pointed ends. In each is a single nucleus. The terms *smooth* and *plain* applied to these cells have reference to the contrast which exists between them and the fibers of skeletal muscle; the difference will be apparent later. When smooth muscle cells contract each one shortens and thickens and, since the majority have a parallel direction, a corresponding change in dimensions may take place over an area of considerable extent.

Movements brought about by smooth muscle are never very rapid. In most cases they can fairly be called gradual or sluggish. When the stomach of a living animal is exposed to inspection creases are seen in its surface and the position of these creases steadily shifts toward the adjoining intestine, but the progress is so slow that in the cat 30 seconds may be occupied in traversing an inch. Contractions of smooth muscle are never sharp twitches; their onset and their disappearance are both gentle and slow. The reader will perhaps question this as he recalls the convulsive character of vomiting movements, but these are not true gastric contractions. They are produced by skeletal muscles bearing upon the outside of the stomach.

Varieties of Muscular Movements.—Muscular movements of all varieties fall into two classes according to their causation. Some are due to the influence brought to bear through the central nervous system. This is true of those made by the skeletal muscles. Every breath that we take is the result of a distinct act on the part of a certain cell-group in the brain. This is not so at all in the case of the beating heart. Here the successive contractions testify to an independent rhythmic tendency resident in the cardiac muscle. In other words, the heart would continue to beat even though disconnected from the central nervous system. We express this fact by saying that cardiac muscle is *automatic* and the same may be said in a general way of smooth muscle.

A ring cut from the stomach of a frog and suspended so that its contractions shall lift a light lever will, under favorable conditions, shorten and relax with a slow rhythm during many hours. The same behavior has been described for the urinary bladder of a cat. The automatic property is an important matter to be reckoned with in considering both the physiology and the hygiene of the alimentary tract. One inference may be drawn without delay: namely, that when we have to

do with a tissue that is fundamentally automatic, the influence of the nervous system may be either to increase or to diminish the degree of activity. The idea that the nervous system excites action is familiar, the conception that it may also abate activity must be borne in mind. Such restraint is called *inhibition*.

Tone.—An organ with smooth muscle in its walls may be much more fully relaxed at one time than at another. When it appears exceptionally large we need not conclude that it is forcibly distended by its contents as we should assume of a rubber bag. The stomach, for instance, may be much more capacious at one time than at another and yet it may exert no more pressure upon the food inside when it is very large than when it is small. The adaptations exhibited by the hollow organs toward their varying contents are referred to as *tone changes*. If the stomach is dilated to accommodate a meal we say that its tone has been lowered. The student must clearly distinguish between such changes and actual stretching. Tone may be defined as a residue of contraction or incomplete relaxation. The conception is one which we shall constantly be called upon to entertain. The equivalent words, *tonus* or *tonicity*, may be used.

The facts of tone variation are well illustrated by the behavior of the urinary bladder. When this container has just been emptied, its cavity is practically obliterated. At another time it may hold a pint. But everyone knows that the urgency of the call to empty the bladder is not by any means proportional to the quantity of its contents. The desire may be strong when the organ is very small. If we had to do with a simple elastic sac the internal pressure would necessarily correspond with the degree of distention but the walls are living tissue and can contract and relax independently of the amount of liquid enclosed. Tone has to be recognized also as an essential property of the arteries, especially those of the smallest order. Variations of arterial tone will call for careful attention at another time.

Tone changes are noted in the heart as well as in the organs in which smooth muscle is present. The heart, like the stomach although within narrower limits, may be a larger organ at one time than at another. If we make use of any method to record the beating of the heart we may find that the rhythmic beats do not rise from a uniform but from a variable base-level. This is to say that the degree of relaxation is sometimes more profound than an average and sometimes less so. Tone changes in skeletal muscle are not so readily apparent as in the other kinds of contractile tissue but there is no doubt that they occur. The consequences are, in this case, somewhat different from those that have been described.

It has been shown that the value of tone changes such as take place in smooth muscle consists largely in adapting hollow viscera to their varying contents. The skeletal muscles do not, as a rule, bend around cavities; usually each one is arranged to cause motion on the part of a bone. There can ordinarily be recognized for each skeletal muscle another, or perhaps more than one, adapted to counteract its tension and to produce an opposite movement. So we speak of antagonistic or opposing muscles in the skeletal system.

Increase of tone in skeletal muscles has, as its main result, the establishment of a greater rigidity and so of a greater resistance to external forces applied to cause motion at the joints. Where smooth muscle with heightened tone tends to diminish the cavity of whose wall it forms a part, skeletal muscle is known to be in tonic contraction by the firmness that is noticed in the affected region and by its own relative hardness. Good posture depends on proper tone maintained by many associated muscles.

CHAPTER V

SKELETAL MUSCLE

The skeletal muscles are of various sizes and shapes. Many are elongated cylinders or prisms; others are in the form of comparatively thin sheets. Most of the muscles of the limbs can be fairly described as belonging to the first class while the other type is found in the walls of the abdomen. The longest muscles extend perhaps as much as 18 inches between attachments, the smallest recognized as individuals are tiny affairs in the cavity of the middle ear. These are only a fraction of an inch in length.

When we observe a muscle in action we can usually recognize that one end is relatively fixed in position while the other is moved by its contraction. The comparatively stationary end is the *origin*, the movable one is the *insertion*. The distinction is not always clear and we can think of cases in which the two may seem to be interchangeable, but there is generally obvious reason to assume a certain type of action. A convenient choice for illustrative purposes is the biceps, on the front of the upper arm. This is the muscle most often exhibited with pride by the schoolboy.

The biceps is attached to the shoulder-blade above and to one of the forearm bones, the radius, below. It tapers toward its extremities, and a little inspection shows that these terminal parts are not contractile, but connective tissue. They are *tendons*. The biceps has two tendinous extensions at its upper end and takes its name, "two-headed," from this fact. The intermediate portion of the muscle is convex in contour and is called its belly. This is the active, contractile part, but it is

necessary to emphasize the teaching that even here connective tissue is present. It exists in a sheath, enveloping the muscle, and it also subdivides it internally, blocking off its substance into many bundles in the way which is so evident in a beefsteak. It is easy to forget that connective tissue is everywhere associated with the contractile; it is in fact indispensable to the mechanism. It may be said to constitute a harness by means of which the innumerable living units transmit their combined force.



FIG. 12.—The biceps is shown with its chief antagonist, the triceps. The biceps bends the elbow and is termed a flexor muscle, the triceps, bringing about the counter-movement, is an extensor.

It will be found upon examination that the moving bones are levers with such relations that the pull of the muscles is generally upon the short arm. It is, in other words, nearer the fulcrum than is the load to be lifted. The organization is therefore one which secures speed and extent in motion at the expense of sheer force. When the forearm is held horizontal and a 10-pound weight is upon the palm of the hand, the actual tension maintained by the biceps and one or two auxiliary muscles must be more like 100 pounds. The student may find himself reluctant to believe this, but a little attention to the proportions of the parts concerned will compel him to assent to the conclusion. The muscles which bring the lower jaw against the upper are so attached as to apply almost their whole power in the region of the molars and a pressure of 270 pounds has been recorded between these teeth.

Muscle Fibers.—Let us now attend to the nature of the living units just mentioned. They are the *fibers* of the muscle. A single one has about the dimensions of a

short piece of hair: it may be an inch long but only $\frac{1}{500}$ inch in diameter. It is a cylinder and so long in proportion to its thickness that our diagrams cannot show both ends and still be broad enough for pictorial clearness. The fiber is a modified cell. Instead of having a single nucleus it has a considerable number of nuclei at intervals near its surface. While most animal cells are practically naked a muscle fiber has a well-defined envelope, the *sarcolemma*. At either end of the fiber the sarcolemma is continuous with the connective tissue. So it comes about that each fiber is a muscle on a small scale; it consists of an elongated body of living contractile substance within a sheath and attached at its ends to non-contractile tissue through which its pull may be applied.

Skeletal muscle is often called *striped* or *striated*. The reference is to fine transverse markings which one sees in the fibers when they are highly magnified. The designation *smooth*, fixed upon the visceral type of muscle dealt with in the preceding chapter, is used because these cross markings are absent from such cells. The striations are not surface marks upon the sarcolemma, but stand for an obscure but highly specialized internal organization of the living matter. Very different interpretations of their meaning have been advanced by different investigators.



FIG. 13.—Portions of four fibers of skeletal muscle. If carried out to their ends these would be several feet long, for often their length is as much as 500 times their diameter. Two are crossed to suggest their relative transparency. The one at the right has been injured and the sarcolemma remains spanning a break in the striated protoplasm.

The disposition of the fibers in a mass of muscle may be curiously varied. They may be laid parallel throughout or they may have quite another grouping. When a muscle has the character known as *penniform* we can recognize the arrangement as possessing the greatest value. An example of a penniform muscle is the

gastrocnemius, the chief calf muscle, as it may be found in the frog. A longitudinal section shows that there is an internal core of connective tissue which is really an extension of the upper tendon by which connection is made with the thigh-bone. From this core the fibers run outward and downward. They are short and seem to be inserted in the superficial envelope of the muscle.



FIG. 14.—A band of parallel fibers compared with a penniform arrangement. The former can lift through a longer interval, the latter with much more force. The pull in the second case is that of a far greater number of fibers.

When the *gastrocnemius* contracts, the external layer is drawn up and the lower tendon (tendon of Achilles) is lifted with it. The central connective tissue is motionless. The core furnishes a place of origin for a vastly greater number of fibers than could be accommodated, if they ran parallel from the knee to the heel. The power of the muscle is correspondingly increased.

At the same time its range of movement as measured at the lower end is much reduced. In effect, a relatively long bundle of muscular tissue, adapted by its shape to have a place in the leg, is given the properties of a short muscle of great thickness. (Fig. 14.)

Muscle Contraction.—Muscles of the order which we are now considering are not automatic. On the contrary they are thrown into contraction because they are connected with the central nervous system which presides

over them. Break the connection just mentioned and the muscle is paralyzed. For experimental purposes we may substitute artificial stimuli for the normal ones which proceed from the brain and cord. Electric shocks are generally employed in such trials. They are preferable for several reasons to other kinds of stimuli. They are relatively harmless to the tissue and they can be accurately graded in intensity.

To study the nature of muscle contraction an isolated

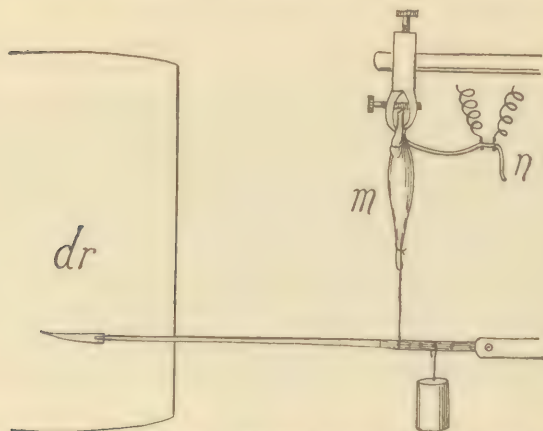


FIG. 15.—*m* is the muscle held in a clamp and connected with a weighted lever the point of which bears on the smoked drum, *dr*. *n* is the nerve carried over electrodes through which it can be stimulated. Stimulation may be applied directly to the muscle.

muscle from a frog's leg is usually chosen. The most suitable for most uses is the gastrocnemius since it is readily separated, with little or no injury, from the neighboring structures. It is left attached above to a bit of the thigh-bone which is held in a clamp. The tendon below is made fast to a lever which the muscle will lift when it contracts. The lever is designed to reproduce the movements of the tendon upon a larger scale. At its free end it is tipped with a point of paper

and when this is made to bear upon a smoked surface, either at rest or in motion, a record of the rise and fall is traced. This is an example of what is called the graphic method in physiology.

Suppose, now, that a muscle has been prepared and suspended above a writing lever. Suitable contacts are provided for the passage of electric currents through the tissue. The experimenter administers a momentary shock. The muscle is seen to twitch, the lever springs upward and falls again. All that can be ascertained by direct observation is that we have to do with a fairly quick and brief response. To learn more than this we

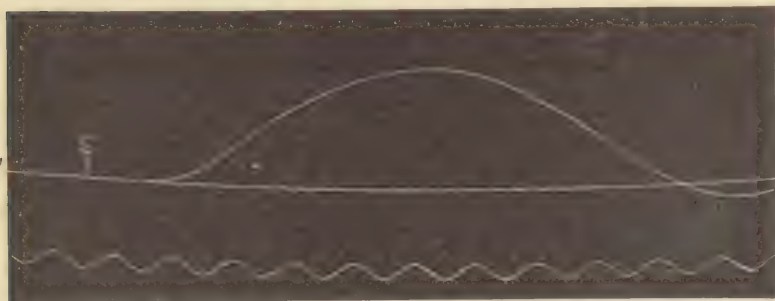


FIG. 16.—Curve of simple muscular contraction. (*Howell.*)

must have recourse to additional apparatus. The smoked paper may be borne upon a metal drum turned by clockwork. If the drum is revolved at a brisk rate while the muscle is made to repeat its sharp twitch a curve will be left which can be analyzed with profit.

The curve traced upon a moving surface when the muscle acts in response to a single stimulus is the curve of a "simple muscle contraction." The speed of the recording surface influences its appearance but not its significance. It will be found to have a definite peak rather than a flat summit. On the average the descending slope of the curve—the record of the relaxation—will be somewhat longer than the ascending part which

indicates the shortening of the muscle. Occasionally the reverse is the case. To translate the curve and its subdivisions into terms of actual time it is only necessary to have a tuning fork with a known rate of vibration which leaves its wavy tracing upon the drum at the same time that the muscle is recording.

If our tuning fork makes 100 vibrations per second, it is likely that the curve described by the lever (moved by a fresh muscle to which one stimulus has been given) will stretch over about 10 of the small waves. The conclusion is that a simple contraction can be executed in $\frac{1}{10}$ second. If this is true 10 stimuli, with uniform intervals, might be given in a second with the result that the muscle would contract 10 times and drop the lever to the base-line after each contraction. As a matter of fact some fusion would probably occur because, in a series of repeated simple contractions, the duration of individual ones tends to increase. Human muscle shows little or no superiority to the frog's in its capacity for rapidly repeated movements. The best that the trained pianist or typewriter can do with one finger is to press a key 10 or 11 times in a second. We are far inferior to flying insects whose wings may beat 300 times or more in the same brief interval.

Summation.—If a second stimulus takes effect upon a muscle which has not completed its relaxation, after answering to a first, it may spring from its partially contracted condition to perform a fresh act. In the tracing the second curve seems to be mounted upon the first and reaches a greater height. The second stimulus may be so timed as to make the later elevation rise from the very peak of the earlier one. Two stimuli of moderate intensity may be more efficient in forcing up the height of contraction than one stimulus, however strong, can possibly be. At least this is true when a muscle raises any considerable weight.

Tetanic Contractions.—As it is possible to follow one stimulus with another after such a short interval that

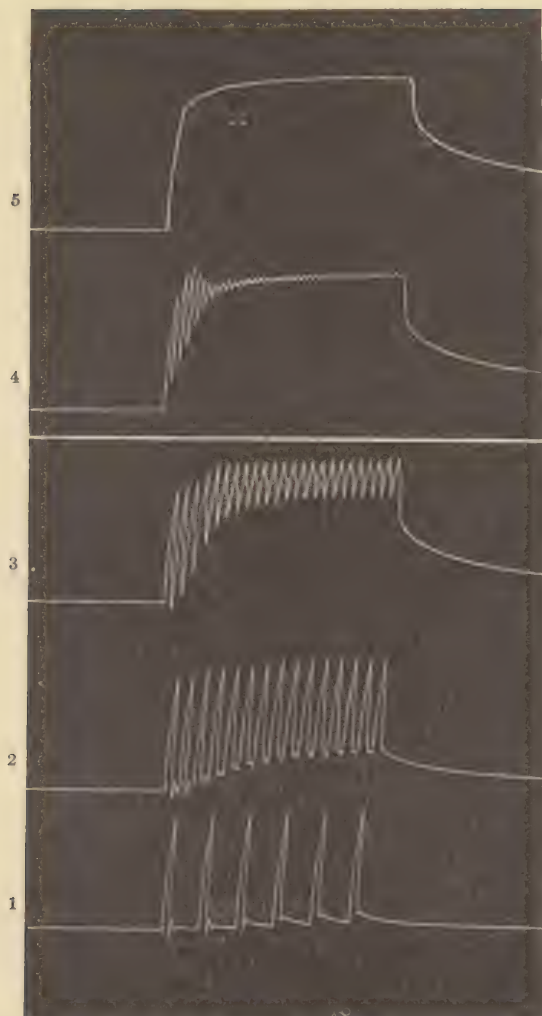


FIG. 17.—Analysis of tetanus. Experiment made upon the gastrocnemius muscle of a frog to show that by increasing the rate of stimulation the contractions, at first separate (1), fuse more and more through a series of incomplete tetani (2, 3, 4) into a complete tetanus (5) in which there is no indication, so far as the record goes, of a separate effect for each stimulus. (*Howell.*)

the muscle does not have time to relax, so a series of stimuli can be given at so rapid a rate that the muscle is held throughout at the height of contraction. Shocks sent in with a frequency of 25 in a second should suffice to secure this result. The tracing obtained from a muscle thus treated has a plateau character and the temptation is to describe such a contraction as continuous. But it is not to be thought of in this way. The seeming continuity of the process is the result of successive physiologic acts of contraction permitting no apparent relaxation to take place. Sustained contractions are common enough in our experience; in fact, they are the rule rather than the exception. Even our briefer voluntary movements are believed to be produced by stimuli which issue in series rather than singly from the nervous system.

A tetanic contraction is, therefore, the response of a muscle to rapidly repeated stimuli and is contrasted with the single contraction which is the response to a solitary stimulus. The name tetanus, in medical literature, means lock-jaw, and since in that disease the chief symptom is the recurrence of muscular spasms the term used by the physiologist is seen to be appropriate. A tetanus may be either complete or incomplete. In the second case relaxation begins after each upthrust but is interrupted the next instant. A jagged record results with the experimental preparation and the contraction is obviously of a tremulous or fluttering character. Strong voluntary contractions are attended by noticeable tremor. This has been attributed to incompleteness of tetanus in the fibers at work, but it may also be due to varying distribution of activity among different portions of the muscles.

Muscular Fatigue.—If a frog's muscle is compelled by stimulation to make a long series of simple contractions, several points of interest will appear in the record. It often happens that the first few contractions are seen to have gained progressively in height. This

indicates that the capacity to respond to stimuli is not at its best when the preparation is absolutely fresh but rather after it has done some work. We have here an instance of "warming up" although it may not be closely comparable with the experience for which that term is used. The word *staircase*, or its German equivalent *Treppe*, is applied to the early contractions which show this gain in height. The *Treppe* is usually limited to a small number of twitches; a maximum is then reached and for a time the contractions are nearly of uniform extent.

Presently, however, the height of the tracings begins to denote a slow decline. We say that the muscle has begun to exhibit fatigue. If we continue stimulating at regular intervals a time will come when no movement can be evoked, but a vigorous muscle will make more than 1000 simple contractions before this limit is reached. If one of these later and reduced contractions is traced over a tuning-fork record, it is found to be prolonged as well as low. Closer observation shows that the shortening has taken place almost as rapidly as in an unfatigued muscle, but that the period of the relaxation has been much lengthened. The frog's muscle when fatigued is accordingly said to show "contracture," that is, delayed relaxation.

What has happened in a muscle which has been forced to work until quite fatigued? To answer this question we must consider the source of the energy which has been set free. The general truth to be borne in mind is that all such energy must be referred to chemical decomposition. A muscle has often been compared with a steam engine in which fuel is burned, heat produced, and a share of the heat transformed to do mechanical work. Recent studies have served to show that the parallel is not so close as had been assumed. Still it has its value.

A muscle removed from the body can receive nothing of importance from its environment except oxygen. Its fuel supply is strictly limited. As it works this

supply will be drawn upon and exhaustion will steadily come nearer. The situation is like that of an automobile on the road. Its possible travel is determined by the quantity of gasoline carried. The isolated muscle cannot be furnished with fresh fuel as the motor car can be. The comparison suggests that a fatigued muscle is one in which the store of fuel is running short. We shall find, however, that this is not the whole story.

A fire may go out from lack of draught as well as from want of fuel. The chemical processes in a muscle which are necessary to cause contraction may be retarded in an analogous way. A deficient oxygen supply will certainly hasten fatigue. Another condition to be given due weight is the possible gathering in the tissue of products generated in the course of its own activity. The draught provided for a fire has a double purpose. It introduces oxygen and the next instant it sweeps away the gases formed in combustion. The blood which is normally flowing through a muscle has a like service. Interrupt the circulation and the oxygen supply is cut off at the same time that provision for removing carbon dioxid is abolished.

Without detailing many experiments that have thrown light upon this matter we may say that muscular fatigue, as observed in laboratory conditions, is much more likely to be due to accumulating waste-products than to imminent exhaustion of fuel. Carbon dioxid is not the only one concerned; another which receives much attention by writers on the subject is a variety of acid (sarcolactic acid) closely resembling that which is formed in the familiar souring of milk. This is certainly produced in active muscles whenever their working is out of proportion to the available oxygen and it definitely lowers their capacity for contraction. Still other "fatigue substances" beside carbon dioxid and lactic acid have been mentioned by different investigators.

If a muscle is in the body instead of isolated from it, the resistance to fatigue will naturally be increased.

The blood, as it sweeps through the small vessels of the mass, enriches the lymph with oxygen and the fibers receive the oxygen from the lymph that bathes them. At the same time the blood is relieving the lymph of carbon dioxid which the fibers have unloaded upon it. In a somewhat indirect way the oxygen brought to the scene by the blood disposes of the sarcolactic acid. Finally, the blood ministers to the muscle and defers fatigue by bringing new offerings of food, especially sugar.

It is easy to conceive of a state of affairs such that a balance may exist between consumption and renewal. If, in addition, the removal of waste-products is adequate a certain average degree of activity may be indefinitely continued without inducing fatigue. This is actually realized in the case of the heart which begins to beat very early in embryonic life and goes on, it may be, for seventy years. We must infer that the decomposition entailed by every beat is perfectly compensated before the next contraction is begun. Some of the muscles used in breathing show a similar ability to go on with serial movements, though there is more variation in their performance than is true of the heart.

In regard to the Treppe an interesting discovery has been made. It is to the effect that the gain in power during the early period of activity is due to minute quantities of the same substances which we call fatigue products. A little carbon dioxid is favorable to the working capacity of a muscle although any considerable increase of the same compound will depress it. The same can be said of sarcolactic acid and probably of still other bodies. The idea that one and the same substance may be classed as a stimulant or as a depressant according to its concentration is one which is of much value as we consider questions of hygiene.

In the laboratory we can study true muscular fatigue, eliminating other elements from our problem. It is

important to point out that we cannot simplify the conditions to the same extent when we deal with the living body. The fatigue which we know by experience cannot be assigned wholly to the muscles. We do not use these in everyday life without using a large part of the nervous system at the same time. We have, therefore, to admit that the flagging of our own powers as we tire of any exercise may be owing to a decline of efficiency on the part of the nervous elements. How many factors we ought to take into account can hardly be estimated at this time but will be more clear later. "A chain is no stronger than its weakest link" and endurance in action will be limited by the failure of any one of the several mechanisms which are in coöperation.

The Energy Transformations in Skeletal Muscle.—

This is a difficult matter and we cannot pursue it far but it would not be wise to omit all discussion of it. We know that oxidation goes on and that motion results but it has proved exceedingly hard to ascertain what intermediate processes serve to connect the two. We have hinted that the comparison between a muscle and a steam engine is quite faulty and we must now show in what chief respect. In the locomotive oxidation yields heat and a part of the heat energy is presently transformed to work. Heat arises in working muscles also and is more or less proportional to the intensity of their action. The temptation was to assume that in this case, as in the other, all the energy set free existed at first as heat and that a fraction of it, an instant later, was applied to the performance of work. The earlier theories were designed to show how heat might be converted into movement by the muscle.

Recent studies in which methods of extraordinary refinement have been used seem to prove that most of the heat developed in connection with the execution of a simple contraction arises *after* the movement. The inference is that the oxidation does not immediately

precede contraction but comes in its wake. Yet we believe as firmly as ever in the conservation of energy and that there is a correspondence between the work done and the fuel consumed. Are there any analogies which can be employed now that the steam engine has failed us? We shall find that there are.

If oxidation follows muscular movement we must conclude that its purpose is to make ready for subsequent action. Some of the energy liberated must become latent in some way and so be held ready for release either shortly or after some time. This is not an unfamiliar condition in the field of mechanics. In the pile driver, for instance, the engine works to lift the weight which may then be hung at the top of the guides and let fall whenever desired. The oxidation has taken place *after* the fall of the weight upon the pile. To be sure, it has to precede the next descent, but an indefinite time may pass before this takes place. So, in the case of the air brake, preparation is made by pumping air into containers, but this may be done long before the occasion for using the brake. When it is set there is no call for the sudden burning of fuel, but directly after the train has been stopped we hear the pump at work, preparing the system for later service.

The muscle may also be compared with an electric power house in which there are storage batteries. The engines are run when convenient to drive the dynamos and charge the batteries. These will give back energy at any time in connection with chemical changes in their cells. It will be found that this is quite closely analogous to the case of the muscle. The simplest image that we can select is that of the bent bow, drawn back and held in readiness for letting go. We must remember that when a muscle is in tetanus the oxidation that follows each momentary act of contraction is so closely followed by another movement that the order of the processes is obscured. The fibers of such a muscle are like a legion of archers, discharging arrows as fast as they can handle

their weapons. The spectator would see the flight of the arrows and might not pause to reflect that the force applied by the marksmen is opposite in direction and imparted in the intervals between the volleys. The period of relaxation is not marked by a suspension of activity on the part of a muscle but is occupied by a most important readjustment.

The Economy of the Contractile Process.—Calculations are often made with reference to steam engines with the object of discovering how great a part of the total energy represented by the coal can be converted to actual horse-power or work. It has not been possible to raise the proportion thus convertible much above 15 per cent. As a rule something like seven-eighths of the energy liberated when the fuel is burned escapes the application which the engineer would like to make of it. Most of it goes up the chimney as heat. Similar computations can be made for the skeletal muscle for here, too, we have a mechanism in which fuel is consumed and heat and work produced.

Under the best conditions a muscle can make a much better showing in this respect than the engine. A record of about 50 per cent. has been attained with simple contractions. With tetanic contractions the efficiency is lower and often of the same order as that of the engine. It is not practicable in a work like this to detail the ingenious methods by which these facts have been established. A man going up a mountain is probably forced to radiate to his environment and make latent by evaporation as much as three times the heat which would be equivalent to the measurable work accomplished.

Skeletal Muscles as Heat-producing Organs.—The production of heat we have been discussing is not to be thought of as an absolute and unfortunate waste. Human beings and warm-blooded animals usually have to maintain body temperatures many degrees higher than those of their surroundings. Such a condition can

be kept up only by the generation of heat in their bodies and this evolution goes on chiefly in the skeletal muscles. A contribution to the total is also made by the heart and the glands. When the outside temperature equals or exceeds that of the body the unavoidable continuance of internal heat production does add to the difficulties of the situation. On the other hand, an animal whose muscles have been removed from the control of the nervous system, so that they cannot be called into play on occasion, has little resistance to cold. We save ourselves from freezing to death—partly, to be sure, by extra clothing—but largely because when we feel cold we are instinctively active. If we try not to be so we soon shiver or grow tense in the attempt to remain still. Either shivering or tension means muscle contraction; so nature refuses to be cheated.

CHAPTER VI

SKELETAL MUSCLE AND THE NERVOUS SYSTEM

The statement has been made that the contractile tissue of the heart and also that which we call smooth muscle may be considered "automatic"—that is, having an inherent tendency to keep contracting and relaxing. These tissues are subject to nervous regulation which may either augment or repress the native property. Skeletal muscle has been said not to be automatic. All its movements in life are caused through the central nervous system and we must now give our attention to this relationship. It is one which holds as truly for the single muscle fiber as for the multiple arrangement.

Each muscle fiber is believed to have one and only one point at which the stimulus from the nervous system affects it. This is about its middle. A theoretic advantage may be connected with this position: the whole length of the fiber will be more quickly involved if it is "touched off" at an intermediate point than it would be if it were excited at one end. The disturbance, spreading in two directions along the fiber, will traverse it in less time than if it ran from one extremity to the other. However, the saving of time is less than would be supposed and is perhaps of no practical significance. The point at which the stimulus is

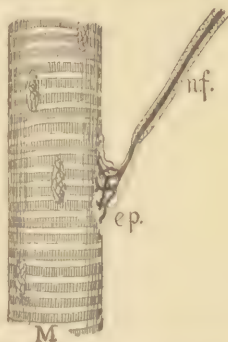


FIG. 18.—The segment is from a fiber of skeletal muscle near its middle. The motor nerve fiber (*nf*) comes into relation with the muscle protoplasm through the peculiar junction known as the motor end-plate (*ep.*).

imparted is known as the *motor end-plate*. It is the junction of a nerve fiber with a muscle fiber.

From what has been said it will appear that every muscle fiber is reached by a nerve fiber. These nerve fibers, individually too small to be visible, come to a given muscle in its motor nerve which contains so many of them that it is a cord of some size. We must not conclude that a muscle having 100,000 fibers will receive an equal number of nerve fibers from without. The nerve fibers branch freely before uniting with the contractile units and the result is that from 10 to 100 muscle fibers may be governed through a single fiber such as exists in the nerve outside the muscle. If this were not so, nerves would be much larger than they are in reality.

Nerve Fibers.—A nerve fiber is more slender than a muscle fiber and it is likely to be a great deal longer.



FIG. 19.—Two nerve fibers shown diagrammatically especially to emphasize the continuity of the axon. A detail, further enlarged, to suggest fibrils in the axon.

Moreover it is a compound affair and cannot be regarded as a modified cell. At first glance and ever after it suggests an insulated wire. There is a central core, the *axon*, and there is no doubt that here, as with the wire, it is this internal core which is the essential conductor. Around the axon there is a sheath of fatty substance. External to this again there is an extremely thin outer sheath, the *neurilemma*. The axon is continuous throughout the longest fiber but the fatty sheath is a jointed structure with interruptions of which there are about twenty-five to the inch. These interruptions are known as *Nodes of Ranvier*.

One must distinguish clearly between a nerve fiber and a nerve. The nerve is a cable and may have bound up in it many thousand fibers. Nerves are traced by the dissector and with the unaided eye; fibers require high powers of the microscope to reveal their character and numbers. For the present our interest is in such a fiber as leads to a moderate number of end-plates in a skeletal muscle. The axon of this fiber is a conductor of something to the dependent muscle fibers, but what is it that it conveys? How is the stimulation made effective? These are questions that we cannot answer very fully. It will be helpful to begin by excluding certain conceptions.

Nature of the Nerve-impulse.—First of all, that which passes along fibers of the nervous system is not matter but energy. We do not have to do here, as in the blood system, with tubular conduits. An early and crude notion was to the effect that fluid pulses travel along the nerves. The idea was quite elaborately developed and had its value but only as a provisional symbol. We must likewise avoid thinking of nerves as though they were cords to be pulled upon. The expressions "nerve strain" and "nerve tension" encourage this view but they are figurative. A man is said to have tense nerves when the tension is really in his muscles. Under such circumstances the muscular state manifests a corresponding nervous condition but is not to be identified with it.

Another temptation is to think of the nerves as conductors of electricity. There is, in fact, nothing of human construction so suggestive of the nervous system as is the telephone equipment of a community. But it is generally held that the form of energy which nerves transmit cannot be the electric current as ordinarily understood. It does have electric accompaniments and it has lately been urged that the impulse itself is essentially electric. If this is true, however, the conditions prevailing in nerve fibers are still so peculiar as to forbid

close comparison between them and telephone wires. A wire can be cut and spliced, when it will conduct nearly as well as before. A nerve cannot be reunited after cutting so as to resume its service.¹

The velocity at which the impulse passes along the nerve has been measured quite accurately. By suitable apparatus it is possible to show that when a considerable length of nerve is used to excite contraction in a muscle the response is distinctly less prompt than when the stimulus is applied close to the muscle. The difference in time between the two trials must be attributed to the employment of an extra length of nerve in the first case. By a simple calculation it appears that the rate of transmission in the nerve of a frog at room temperature is in the neighborhood of 100 feet per second. This is the speed of an express train running 70 miles an hour. Higher rates seem to be reached in the warm-blooded animals but the maximum is less than the velocity of sound waves in the air, and is insignificant by comparison with the speed of light.

The term nerve-impulse which we usually use to denote the energy carried along a nerve does not bind us to any particular theory as to its nature. Whatever it is, it is rapid enough to insure prompt reactions in animals of ordinary size. Furthermore, it is not appreciably exhausting to the fibers concerned in forwarding it. Muscles fatigue with use, as we have seen; nerves seem nearly if not quite proof against fatigue. The reader should recognize that this statement is limited to the fibers on which our attention for the present is fixed. There are other elements in the nervous system which probably suffer wear and tear when in use. The susceptibility of these structures to fatigue will be discussed at another time.

¹ Surgeons often reunite nerves which have been cut and eventually secure a renewal of action. But this does not contradict the statement above; new fibers must grow across the gap and extend to the terminations before the result can be obtained. (See p. 90.)

Origin of Nerve-impulses.—We can now proceed to investigate the place of origin of the nerve-impulses by which muscles are thrown into action. We have pictured a cluster of muscle fibers whose end-plates are supplied by the branches of a single nerve fiber. Whence does this fiber come? The answer will depend upon the position of the muscle in the case so we will assume a definite example. Suppose that it is the biceps of the arm. A motor fiber ending in this muscle could be traced back to the intricate commingling of nerves in the neck to which we give the name of the cervical plexus. The fiber could, theoretically at least, be shown to have come by an unbroken course through this maze and to have originated in the spinal cord near the same level.

If we had chosen a muscle of the head—for instance, the masseter which acts upon the lower jaw—we should have found the selected fiber to have come through one of the openings of the skull and to have arisen in the lower part of the brain. The motor fibers for the leg muscles come from the lower levels of the spinal cord. Since all the skeletal muscles excepting those of the head derive their motor supply from the spinal cord we must attend now to some of the features of this part of the nervous axis.

The Spinal Cord and the Spinal Nerves.—It has been previously pointed out that the spinal cord occupies a canal formed by the arches of the vertebræ. The cord is continuous with the brain above, a large opening in the base of the skull providing for the union. Protective membranes, the *meninges*, with more or less included fluid, envelop the cord. The spinal nerves spring from it in pairs; thirty-one nerves on each side. They go out through notches in the bones, one pair between each two vertebræ. The cord is not so long as the canal in which it is lodged; the result is that the nerves which are to leave the lower end of the canal

descend within it for some distance below the extremity of the cord.

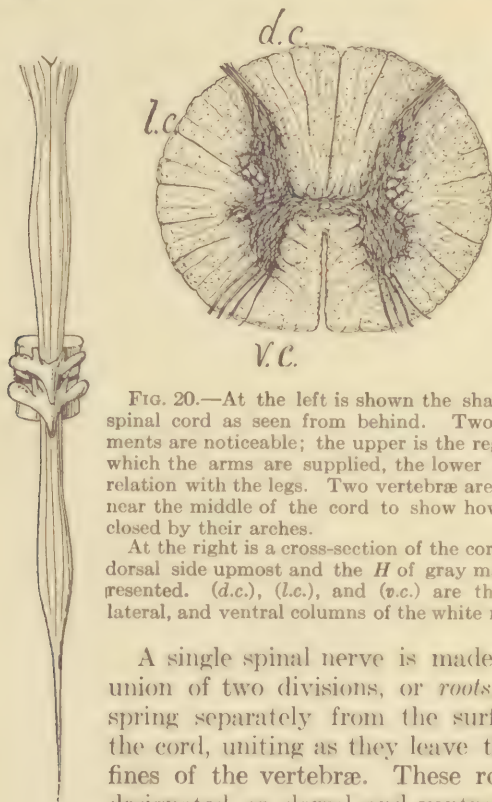


FIG. 20.—At the left is shown the shape of the spinal cord as seen from behind. Two enlargements are noticeable; the upper is the region from which the arms are supplied, the lower stands in relation with the legs. Two vertebræ are sketched near the middle of the cord to show how it is enclosed by their arches.

At the right is a cross-section of the cord with its dorsal side upmost and the *H* of gray matter represented. (*d.c.*), (*l.c.*), and (*v.c.*) are the dorsal, lateral, and ventral columns of the white matter.

A single spinal nerve is made by the union of two divisions, or *roots*, which spring separately from the surfaces of the cord, uniting as they leave the confines of the vertebræ. These roots are designated as dorsal and ventral. The motor fibers which it is our present interest to trace emerge from the cord in the ventral roots. We may anticipate a later discussion to the extent of saying that the dorsal roots are composed almost wholly of fibers whose service is to carry impulses *into* the central axis. There are thus two great classes of nerve fibers, those which bear impulses outward, *efferent* fibers, and those which convey impulses

inward, *afferent* fibers. Not all the efferent fibers emerging from the cord in the ventral roots are of the motor type which we are just now describing, but a large proportion of them are of this sort.

White and Gray Matter.—When a cross-section of the spinal cord is examined with the naked eye two kinds of tissue are apparent in it. These could be recognized long before the workers with the modern microscope had resolved them into their elements. They have been known respectively as the white and the gray matter. The two exist not only in the cord but in the brain. In the cord the gray matter is found in all sections in a form which has usually been likened to the letter H. A diagram will show how, by its presence, it breaks the white matter into three *columns* in either half of the cord, the dorsal, lateral, and ventral (Fig. 20.)

The white matter of the cord and brain is nearly identical with the substance of the nerves. That is to say, it is composed of conducting fibers, closely packed in parallel bundles. If it were not for the gray matter in the spinal cord we should be justified in calling that structure the greatest of all the nerves. In fact we may call it so but we must add that it is more than this. To find out why we must examine the gray matter.

The structure of the gray matter is peculiarly intricate and obscure. There is much disagreement with reference to its finer features. Perhaps the first thing which commands attention when it is viewed under the microscope and compared with the white matter is an apparent looseness of texture. There are nerve fibers to be seen, but they are rather widely separated and do not have a common direction. The most conspicuous bodies visible are the so-called nerve cells. These are of several types. As a rule the following characters may be recognized. The outline is singularly broken, each cell having a number of processes. Most of these can be shown to subdivide into extremely

slender twigs, the *dendrites*. The nucleus in a nerve cell is usually large and prominent.

The axons of nerve fibers are outgrowths of nerve cells. This is a most important truth to grasp for it explains the relation between gray and white matter. While the great majority of the processes which spring from nerve cells branch out to form dendrites, as just described, certain other processes acquire the sheaths that appertain to nerve fibers and run on without interruption for long distances. We can return now to

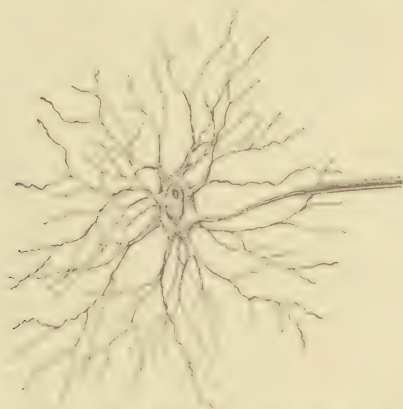


FIG. 21.—A common type of nerve cell giving rise to the axon of a nerve fiber.

the motor fibers which we are seeking to trace to their place of origin. The statement can now be made that each of these fibers—so far as its essential core or axon is concerned—is an outgrowth from a cell in the gray matter of the cord or the brain.

Functions of the Nerve Cells.—What, then, are the functions which we are to ascribe to the nerve cells? The impulses which run along the fibers must have come from these cells. The question remains, however, whether the cells have generated the impulses or merely transmitted them. We shall do well to emphasize the

conception that they act as transmitters. But it is possible that they reinforce the energy which they send forward. One may very crudely liken a muscle to a torpedo or mine and its nerve-supply to the electric wires provided for ignition. The nerve cells then figure as batteries to furnish the current. Batteries are gradually exhausted in the production of currents while wires are hardly affected by carrying them. It has been said that nerve fibers scarcely give evidence of fatigue. Nerve cells are believed to suffer some impairment when long in use.

If impulses proceed from nerve cells along motor fibers to the end-plates in skeletal muscle and, upon their arrival, start the contractile process we may be led next to ask: What significance have the dendrites? It is held that they are receptive in their nature, that through them the nerve cells are wrought upon by stimuli. The ordinary motor cell has many dendrites and a single axon—many avenues of approach and only one channel of expression. One is reminded of the teaching familiar to childhood that we have each two eyes, two ears, and only one mouth. A nerve cell with its axon and dendrites constitutes a *neuron*.

Nutritive Functions of Nerve Cells.—Whether or not the nerve cells reinforce the impulses which they transmit they have another function which we shall do well to emphasize at this time. They are responsible for the maintenance in normal condition of the axons which spring from them and this is true no matter how long these axons may be. It is a general truth that parts of cells separated from the nucleated portion do not long survive. If we regard a neuron as a cell, the impossibility of preserving the axon when it is cut off from the cell-body appears merely to be a special case of this dependence.

When a nerve is severed a degeneration of the fibers follows and it is found to accord with the following rule. Those portions of the fibers left in connection with their

nerve cells are kept normal; degeneration occurs in the parts of the fibers which have been deprived of this connection. In most nerves all the related cells are in the central axis or in ganglia—detached nodules of gray matter—near it; degeneration will therefore be peripheral to the cut and will involve all the fibers in that direction. The principle of degeneration has had a value for students of the nervous system. It has been practicable to make carefully defined cuts in the brain or the cord and by observing the changes occurring in the course of some weeks afterward to show that in certain bundles the governing cells have been left above and in others below the injury. The animal must be kept alive until the process is completed and then killed for postmortem study.

Regeneration.—A nerve which has been cut and which has lost its normal character throughout the course from the incision to the endings may grow again. In its degenerate condition it is still represented by a strand of modified tissue. If there is no distinct obstacle to the new development an extension of the cut fibers may be effected along their original track. It is certainly remarkable that several thousand fibers may be so guided within their connective-tissue sheath as to make distant and useful connections. Within the central nervous system degenerated fibers are not renewed. This sets a limit to the process of recovery from injuries to the brain and cord. Yet the outlook is often better than might be assumed for supplementary paths are brought into use, sometimes with surprising success.

Fatigue.—How the dendrites of motor cells are brought under stimulation will be the subject of the next chapter. At this point we shall extend somewhat the ideas of fatigue previously developed. It has been stated that only in laboratory experiments can we observe the behavior of a muscle apart from its nervous connections. Muscle fatigue, pure and simple, is unknown to our individual experience. There is reason

to believe that the end-plates are vulnerable parts of the association and may set a limit to our voluntary performances. A common experiment makes this appear probable. Suppose that a frog's muscle is prepared with its nerve. We can then choose whether we will apply our electric shocks directly to the muscle substance or to the nerve which will carry to the muscle the effects of our stimulation.

If we stimulate the nerve a great many times we shall witness at length a total failure of response. If we then shift our application to the muscle itself we may find it capable of still further work. Something has evidently



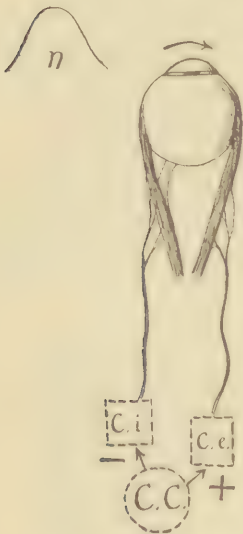
FIG. 22.—A "neuromuscular unit" as defined in the text. The motor nerve cell is united through its branched fiber and end-plates with five muscle fibers. The typic number would be much larger.

fatigued more rapidly than the muscle proper. Other experiments, which we cannot outline here, forbid us to think that the nerve fibers can have been injured and only one conclusion remains possible: that the trouble is with that which is neither muscle or nerve, the end-plate that intervenes between the two. It is quite likely that the comparatively early failure of the end-plates protects the muscles against excessive strain and damage. A muscle which one regards as tired is probably a muscle containing end-plates that are more or less fatigued. There are still other elements in the fatigue of daily life which we shall have to indicate at another time.

Summary.—A skeletal muscle consists of a vast number of working units, muscle fibers, which are modified cells. The activity of these fibers is not spontaneous or automatic but dictated through the nervous system. Each perfect fiber in the muscle has a motor end-plate which is the place where the stimulus is applied. Each end-plate is the terminus of a branch of a motor nerve fiber. A motor nerve fiber, or more precisely its axon, is an outgrowth from a cell in the gray matter of the nervous system. Such a nerve cell, upon receiving stimulation by way of its dendrites, sends out over its axon the rapidly travelling form of energy which we call the nerve-impulse.

A system composed of one motor nerve cell, its far-reaching fiber which branches within the muscle, and the cluster of dependent muscle fibers with their end-plates may be termed a *neuromuscular unit*. When this little system is at work, the chief expenditure of fuel substance is in the muscle. It follows that muscular fatigue, in the strict sense, is a possibility. But activity is accompanied by some destructive processes at the end-plates and in the nerve cells. Hence, fatigue at these points has also to be considered. It is probable that fatigue becomes effective in the following order: first, at the end-plates, second, in the muscle substance itself, third, in the gray matter. There is no doubt that the

FIG. 23.—The principle of reciprocal innervation. The right eye is shown; (*n*) is the nose. (*C.C.*) is the symbol of a coördinating center which presides over two subordinate centers. When the eye is to be turned out one of these—(*C.e.*) which commands the external rectus muscle—is excited (+); the center for the opponent (*C.i.*) is inhibited (−) and the tone of the internal rectus is abated. (Page 93)



nerve fibers, as found in the white matter of the central axis and in the nerves, have the greatest resistance to injury by use.

Reciprocal Innervation.—It will be recalled that the skeletal muscles are generally organized into opposing groups. It has also been said that these muscles are rarely so completely relaxed as they can be. In other words, they have tone. Now it is an interesting fact that when a movement is made—perhaps the bending of the elbow—just as the muscles directly responsible for the movement go into contraction there is an abolition of tone in the antagonistic muscles. Thus they are kept from hindering the act. This is an instance of inhibition; it is supposed that the nerve cells presiding over the muscles which show the extra relaxation are restrained at this moment from a habitual, mild activity which expresses itself in the ordinary muscular tone. “The Law of Reciprocal Innervation” is to the effect that when any muscles are thrown into contraction through the agency of the central nervous system their opponents are inhibited.

This law has been verified for the slender muscles which rotate the eyeball. They are six in number. One is so placed as to turn the eye toward the temple while its antagonist can turn it toward the nose. The contraction of either one of these muscles can be shown to be simultaneous with a slackening of its mate. Of course this is true only when the action is controlled through the gray matter; there would be no trace of it if local electric stimulation were employed.

CHAPTER VII

REFLEXES

In the previous chapter we had chiefly in view the part of the nervous system which directly controls the skeletal muscles. The statement was made that the fibers which establish this connection are called efferent (Latin *efferre*, to bear away). There are fibers in even greater number which provide for the conveyance of impulses into the central nervous system from localities external to it. These, as has been said, are called afferent (*afferre*, to bear toward). They are often called *sensory*. An objection may be raised against the term sensory inasmuch as it suggests that there is conscious recognition of the arrival of all the impulses that traverse these fibers. This cannot possibly be maintained.

Receptors.—Afferent fibers are said to lead from receptors to the brain or the cord. A receptor is any mechanism by which external forces can give rise to nerve-impulses. The name may be applied to the simple ending of a nerve fiber that lies exposed to pressure in the skin or it may refer to such elaborate organs as the eye and the ear. The word external which has been used must be applied with regard to the central nervous system. The position of a receptor may be internal as judged by ordinary standards. Thus there are nerve-terminals in the peritoneum which may be stimulated by tension and give rise to pain. Movements of the head may affect receptors in the depths of the temporal bone. Yet it remains true that we are usually concerned with receptors at the surface of the body. The word sense-organ may be used as a synonym for receptor though it is likely to suggest more readily the highly specialized features of the equipment.

The beginner naturally thinks of the sense-organs as existing for the acquisition of knowledge. This is certainly an important aspect of their employment and one which we cannot afford to slight in our later treatment of the subject, but we must recognize first a lowlier type of action. This is the reflex. We must take great pains to define and illustrate what is meant.

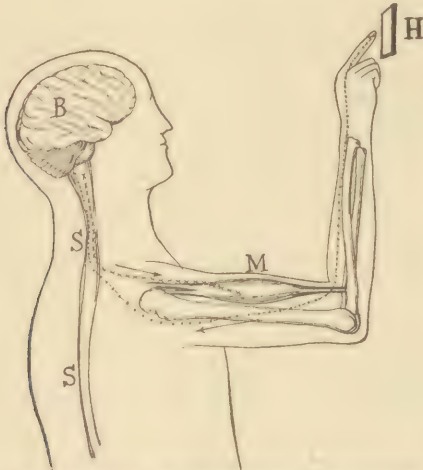


FIG. 24. The principle of reflex action. The subject touches a hot object (*H*). Afferent nerve-impulses travel the route marked by dots and dashes to the spinal cord (*S*). Efferent impulses return promptly along the route marked by little crosses to the muscle (*M*), which coöperates with others not shown to withdraw the finger from the stimulating surface. The situation of the coördinating center is left undetermined, as far as this diagram is concerned, whether in the brain or the cord.

Examples are numerous enough but they are apt to admit of misconceptions.

A *reflex act* is one which is executed in response to an external stimulus. It is desirable to add that it is an act not requiring attention. Take for instance the case most often cited, that of the quick withdrawing of the finger from a hot object. A child who made the trial would probably say that he felt pain and took his finger

away accordingly. But there is every reason to think that this is a false interpretation of what happened; the movement occurred and the pain was felt afterward. There was no reasoning process, no entertainment of a wish, before the finger was pulled away. Turn to the case of the narrowing of the pupil when one raises the eyes toward the window. Here is an act which cannot be performed at will and one which may not be attended by any well-marked sensation. It is one of the best illustrations of the reflex.

We are attempting to enforce the teaching that reflexes do not depend on will or attention. Another way of saying the same thing is that they are the result of structure rather than intelligence. A child might think that a mouse was seized by a trap because the trap desired to make the capture. An older person knows that the trap necessarily snaps upon its victim when a certain spring is pressed. Its structure and not its will is responsible for what takes place. To an extent that is rarely appreciated this is true of the nervous system. It is because its reactions are so timely and serviceable that we find it difficult to look upon them as mechanical.

We must now consider the simplest combination of elements that can account for a reflex. There must be first of all a receptor on which the causative stimulus can be brought to bear. This may be nothing more than the exposed ending of an afferent fiber, as has been said. There must be, second, a path to the central nervous system. Theoretically a single afferent fiber will suffice. If this fiber is one which enters the cord it will be found to pass in by one of the dorsal roots. Each of these roots has, just where it parts company with the ventral root, an enlargement or *ganglion*. Study with the microscope has shown that the fibers of the dorsal root run unbroken through the ganglion, but each one in passing connects by a side branch with a nerve cell within its compass. These cells have no dendrites.

The fiber which we have chosen as a type of its order continues from the ganglion to the dorsal portion of the cord. Within this part of the nervous axis it is said to branch into an ascending and a descending division. These run in the dorsal columns of the white

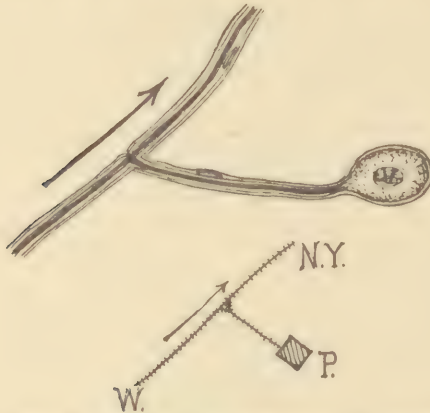


FIG. 25.—Above is shown the relation between a cell-body such as is found in a dorsal root ganglion and the associated afferent fiber. The arrow suggests the course of passing impulses. Whether these actually visit the cell-body has been much discussed. The problem recalls the situation represented below: the traveller from Washington (W.) to New York (N. Y.) may be carried into the Broad Street Station in Philadelphia (P.) or he may be taken past the junction point without making the detour.

matter. Here we have evident provision for the introduction of impulses into the cord and we know the cells of the neuromuscular apparatus are close by. It remains to show how a connection can be established.

It has been shown by the histologists that the afferent fibers in the cord send branches at intervals into the gray matter. The manner of their ending is somewhat in doubt but in all probability they lead to the dendrites of various cells. Impulses led into the nervous system by afferent fibers can thus be carried to the receiving processes of those nerve cells which

preside over the muscles. The linked system of afferent and efferent units is said to constitute a *reflex arc*. Some investigators think that the dendrites are continuous with a network everywhere present in the gray matter and that the fine terminal branches of

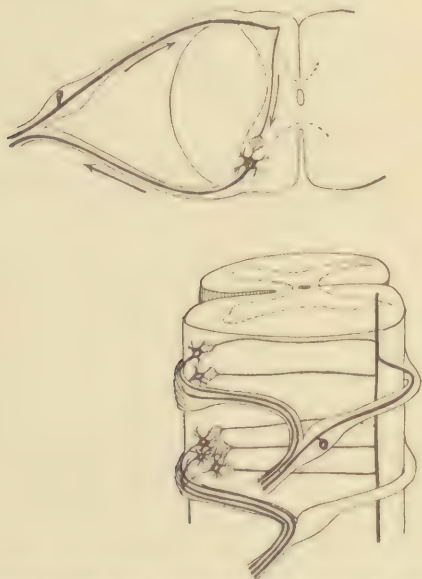


FIG. 26.—The upper figure suggests the simplest possible basis for reflex action. An afferent fiber, entering through a dorsal root, comes into relation with the cell-body giving rise to a motor fiber. This leaves the cord by way of the ventral root.

The lower figure shows the branching form of the afferent fiber and the possibility that it may play upon a number of motor cells at different levels.

the afferent fibers also run into this network. Such a view permits the belief that an impulse may wind its way through the gray matter between its place of entrance and the place of its ultimate escape without any interruption.

It has been held more generally that the impulses

which come out to call the muscles into play are not the same impulses that went in a moment before. They are supposed to have had their origin in particular acts or "discharges" of the motor cells under the influence of stimuli applied to the dendrites. Whichever conception finally prevails we must believe that there are paths of easy transmission between certain afferent and certain efferent channels. It is these paths which make the reflexes under most conditions so advantageous.

Synapses.—The term synapse is used to denote the junction of two units in the nervous system. A synapse is said to exist where the fine terminations of an afferent fiber are joined to the dendrites of a motor cell. It is not certain how far this meeting of the two structures is a literal joining but it is a junction from the standpoint of functional capacity. The nervous system comprises an innumerable host of elements each influenced by a number of others and influencing still different ones in its turn. We say that the communication is through synapses and we picture them as in the diagrams that accompany this chapter. We have at least the same right to do this that the organic chemist has to his molecular formulæ.

There are two or three properties which we associate with synapses and we cannot reason clearly about the working of the nervous system excepting as we keep our faith in these characters. First of all, we believe that synapses transmit effects in only one direction. They have been described as having a "valve action." A nerve cell, therefore, cannot affect the cells which affect it but always plays upon others and these in turn must send impulses over new courses. The student is likely to think that it is the nerve fibers which have this significant polarity but it is not; the fibers can conduct in both directions. It is the synapses which refuse to reverse the transmission.

Another property of the synapse is that of variable resistance. It is clear that the nervous system reacts

much more readily at some times than at others. Stimulants like coffee and strychnin make it easier to evoke reactions. Depressants like alcohol in considerable doses, or the anesthetics, suppress the reflexes in a definite order. We say that the stimulants lower and the narcotics raise the central resistance and we have reason to think that the changes are most marked at the synapses. If the adjustments are to be made for the best interests of the organism the average resistance of the nervous system must be neither too high nor too low. If it is too high the stimuli will fail of due effect, while if it is too low the responses will be exaggerated and disorderly.

A person who is sensitive to coffee may "jump" at the slamming of a door when he is under the influence of the stimulant. This is an unprofitable reaction. A man poisoned with strychnin may be thrown into exhausting convulsions by very slight causes. These are examples of reflex action but they no longer show it as ministering to the welfare of the body. At the other extreme we have the grossly intoxicated man who cannot be roused to meet an emergency. Central resistance must be of a medium grade if all is to go well with the individual.

A subject who is described as "nervous" is one whose resistance is more or less lowered from the normal. He will be unreasonably disturbed by external conditions which a more robust person readily ignores and he will tire himself by countless reactions which were better not carried out. Low resistance is seen to be opposed to conservation of one's resources. It is undoubtedly more common as a constitutional fault than a high resistance which must be indicated by stolidity of temperament.

Resistance and Coördination.—Reflex acts are, in most cases, clearly coördinated. That is to say, a number of muscles are used in their execution and their effects are combined for a common end. Some muscles

bear the brunt of the duty while others support them inconspicuously. Certain ones act in advance of others, for coördination is a matter of sequence as well as of combination. The facts observed can be explained upon the basis of "graded synaptic resistance." When a stream of afferent nerve-impulses enters the central gray matter many possible ways lie open to their further flow. But some of these paths are relatively easy and others difficult. The impulses which find a free passage dictate the more powerful muscular responses; those which encounter a greater hindrance find a more limited expression on the efferent side.

It has been shown that the convulsions of strychnin poisoning, already referred to, are the result of a reduction of resistance in the central stations such that the paths which are ordinarily impossible to penetrate are freely opened while those that have normally a high resistance come to have no more than the beaten tracks. We should anticipate just such a result as that which we actually see, opposing muscles straining uselessly, one against another.

Resistance and Habit.—A reflex act is one which is determined by circumstances and by the organization of the nervous system. The same can be said of a habit. A strong light keeps the pupil contracted and a dish of candy at the elbow causes one to keep taking pieces from it. The principle is similar. But we can usually distinguish without confusion between a reflex and a habit. We keep the first term for those reactions which are inborn or acquired very early in life by all normal individuals. Habits are established later and are more variable. They are personal while reflexes are racial. It is plain, however, that the fundamental condition for a habit is a path of low resistance which favors a certain action when definite stimuli are operative.

The reflex principle is recognizable in nearly all our behavior. We do not like to have it so for it seems to make us creatures of circumstance rather than masters

of our situation. Yet we must admit that external forces guide us in the performance of many acts which we confidently call voluntary. When we walk, our muscular contractions are modified every moment by stimuli from many sources. Some of these we shall have to analyze a little later. A child who is painfully copying a word from the blackboard is really making movements which are shaped by the visual stimuli he receives. But we feel instinctively that it is a long remove from the simple reflex to an instance like this. The question that cannot be put aside is: What is our will and how far is it a positive force in shaping our conduct? The physiologist defers to the philosopher at this point, but as a human being he knows that one's conscience and one's fellow men applaud a faith in one's moral freedom.

If an act is not to be classed as reflex, in any degree whatever, it must be one in which the origin is clearly central and unaided by any afferent impulses. We are disposed to think that this condition is realized in those actions which we call voluntary; yet from another point of view these can be regarded as *delayed reflexes*. They are determined by external stimuli some of which may have been brought to bear a long time before the occasion. A man somewhat suddenly decides to walk up a hill to enjoy a prospect which he has seen the previous year. We describe the act as voluntary but at least one of the factors concerned in causing it is the impression made upon his nervous system at the time of his earlier visit. So the discussion of reflexes leads not only to the problems of habit but to those of memory. This subject will be more advantageously considered in connection with the cerebrum.

Examples of Reflex Action.—We have spent a good deal of time in treating the topic in general terms. Let us now turn to some specific illustrations. What are some of the reflexes exhibited by a baby and how do they make for its welfare? One thinks immediately of the sucking reflex. The infant sucks vigor-

ously whatever is put between its lips. In the natural course of events this reaction, joined with swallowing, insures a supply of food. As it eats it frequently chokes and coughs; the cough is a reflex which prevents the entrance of foreign materials into the breathing passages. A similar reflex—sneezing—is calculated to expel obstructing substances from the nose. Vomiting is a reflex which relieves the overfilled stomach. Crying has a less obvious function unless we assume that it secures the attention of the parents to needs which the child by itself cannot satisfy.

Some of the reflexes which are prominent in the baby are disguised or replaced by others during the period of growth. Sucking ceases to be a predictable performance. Crying is less and less readily induced. The other responses which we have mentioned continue to occur. So, too, the reactions of the pupils and the withdrawal of parts of the body from objects that threaten injury are retained. In the course of a year or two the child has the capacity to keep its feet and to walk, attainments based largely upon the development of reflex mechanisms.

Reflexes Other than Movements.—So far we have spoken of reflexes as though they were necessarily acts of the muscles. The conception must now be made broader. Certain reflexes have a negative or inhibitory character. A dash of cold water may cause one to hold the breath momentarily and perhaps at the same time the heart may “drop a beat.” The suspension of breathing and the omission of the heart’s contraction are true reflexes, but instead of being movements they consist in the *suppression* of movements which were due to occur.

There are also reflexes which are executed by glands instead of muscles. A gland is an organ which prepares and discharges some chemical product. Either the action of the gland or its product may be described by the word *secretion*. Some glands, like the kidneys and the liver, continuously evolve their secretion; others

nearly or quite intermit activity. Glands of the latter type are often found to be as distinctly subject to nervous government as are the skeletal muscles. The nerves which stretch out to them from the central organs are spoken of as *secretory nerves*. They are efferent but not motor according to our definitions.

One of the most familiar examples of the reflex excitation of secretion is afforded by the flow of tears when this results from a cinder in the eye. As there are winking movements at the same time we have here a

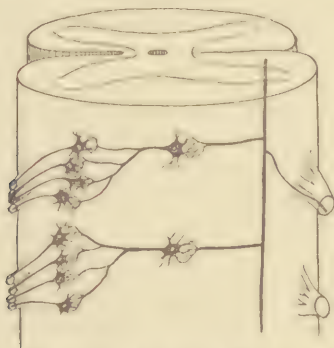


FIG. 27.—This differs from the second diagram in Fig. 26 in the following respect. The afferent fiber does not connect directly with the motor cells but with intermediate or association neurons which extend the effect of the original impulse to groups of efferent elements.

particularly good demonstration of two kinds of reflex action. When the tears start from emotional causes the reflex character of the act is not so plain. A hot or an acid fluid taken into the mouth produces a reflex secretion of saliva. Warming the skin will call forth a reflex discharge of perspiration.

Psycho-reflexes.—In characterizing the standard reflex we insisted that consciousness does not enter into it as an essential feature. We may notice our own reflexes but to observe is not to control them. Often they run counter to our desires; we may be compelled

to cough or sneeze when we would much rather not. Yet there are reactions which we are inclined to call reflex which nevertheless depend much upon the coloring of our consciousness. Take, for example, the watering of the mouth at the sight of delicious food—or of a lemon. Here is a response which is determined by external stimuli but which would not take place in an unconscious nor even in an inattentive subject. The secretion of gastric juice normally accompanies the taking of food but only when there is an element of pleasure. The term *psycho-reflex* is applied to such adaptive changes as these.

The Position of Reflex Arcs.—Our conventional diagrams usually represent segments of the spinal cord as containing the synapses through which reflexes are brought about. We are entirely warranted in this representation, for certain reflexes can be mediated by the spinal cord when it has been separated from the brain. Still, it would be wrong to leave the impression that the cord, in the higher animals, plays the leading part in coördinating incoming with outgoing impulses. The reflex principle is recognized in the brain as well as in the cord and, in our own case, reflexes that are purely regulated by the cord are not usual.

Association Units.—A diagram modified to suggest the path followed by impulses when the brain figures in reflex action should show more than two orders of units. Thus far we have pictured the afferent element as bringing its influence to bear directly upon the efferent. It is not likely, even in the cord, that this simple relationship is the common one. Intermediate nerve cells are ordinarily concerned in the transmission. If this is so, then, as a rule, more than one order of synapses will lie in the path. The intermediate cells, which are not clearly afferent or efferent, have been called *adjustors* or *association units*. As more and more of these are introduced we have more tendency toward varia-

tion in reflex action and we find that we are moving from a lower to a higher type of nervous system.

Reflex Time.—We can measure with great accuracy the time that elapses between the giving of a stimulus, such as an electric shock, and the beginning of a reflex movement in response. The trial is often made for the wink. The shock is applied to the eyelid and the twitch that follows makes a written record. By means of the tuning fork the interval can be estimated. It is likely to be about 0.05 second. Many reflexes are slower, few, if any, are faster than this. The course run by the nerve-impulses from the eyelid to the lower part of the brain and back to the muscles is a short one; most of the time seems to be consumed at the synapses and in the nerve cells rather than in transit.

If the wink following an electric shock is not involuntary but made “on purpose,” as we say, the delay is something like three times as great as with the pure reflex—say 0.15 second. It is then what we call a voluntary *reaction time*. The impulses must have gone over much longer and more interrupted routes.

CHAPTER VIII

THE BRAIN

The student should now be able to picture to himself the following large features of the central nervous system of man. The brain is enclosed within the skull and the spinal cord descends from it through a bony canal formed by the arches of the vertebræ. From the cord spring to right and left 31 pairs of nerves. Each one is a cable composed of thousands of fibers. Somewhat more than half these fibers are arranged to convey impulses from receptors to the cord; the remainder are used to carry impulses out to muscles and glands. (Muscles and glands are sometimes called *effectors*.)

Close to the cord each spinal nerve cleaves into a dorsal and a ventral root. The dorsal root bears a ganglion containing the cells with which the afferent fibers are united. The ventral root is made up almost wholly of efferent fibers. It will be seen that a spinal nerve, considered external to the place of union of its two roots, is mixed in character, containing both afferent and efferent fibers. When a nerve branches, its fibers do not branch but are merely parted. Yet nerve fibers may branch, as we have seen, within the central nervous system and also, in the case of the motor elements, when they approach the end-plates in skeletal muscle.

As there are spinal nerves springing from the cord so there are nerves which originate from the brain. These are known as the cranial nerves. They emerge through openings in the skull and are distributed to localities in the head and neck. One of them, on each side, departs from this rule since it runs down into the trunk. This is

the *vagus*, the tenth in the series. In all there are twelve pairs of cranial nerves. They are of very unequal size and do not show the regular separation into roots that has been described for the spinal system. In the cranial nerves there is an overwhelming preponderance of afferent fibers. This is associated with the existence of the important sense-organs of the head, the eye, the ear, and the nose.

The Human Brain.—By far the largest part of the cranial cavity is occupied, in man, by the great mass of nervous tissue which we call the *cerebrum*. This



FIG. 28.—The human brain from the left. The main mass is the left cerebral hemisphere. The cerebellum, with its narrow convolutions, is below and behind. The medulla bears the stumps of several cranial nerves.

is the “highest” division of the brain in an anatomic and in a physiologic sense. At the first glance one is impressed by its curiously convoluted surface. It is deeply scored by winding furrows. A profound cleft, running longitudinally in the mid-plane, divides it

into two hemispheres, right and left. The cerebrum is united below with the spinal cord by means of an intermediate link which is conveniently referred to as the *brain-stem*. Several subdivisions can be recognized in the brain-stem and mention may be made of the one which is next the cord. This is the *medulla*.

At the back of the cerebrum and overhung by it is

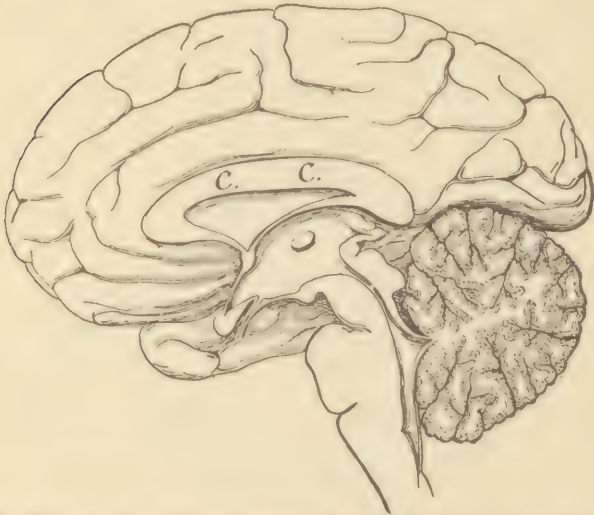


FIG. 29. — The brain cut lengthwise in the mid-plane; in other words, the right half seen from the left. Again the cerebrum is the chief mass; the arched structure (*c.c.*) is the chief bond between the hemispheres. The cerebellum presents a leaf-like pattern. Cavities can be traced in the brain-stem.

a rather large division of the brain known as the *cerebellum*. Its surface is marked by numerous fine corrugations. The cerebellum is furnished with abundant connections with the brain-stem and so, less directly, with the cerebrum above and the cord below. The general ordering of the parts of the brain is best appreciated from a diagram of a median section, or, better still, from a model which can be parted in this plane.

The Cranial Nerves.—Of the cranial nerves, only one pair join the cerebrum. These are the *olfactory nerves*, diffuse collections of fibers which lead into the brain from microscopic receptors in the upper part of the nasal passages. As the name implies, these nerves

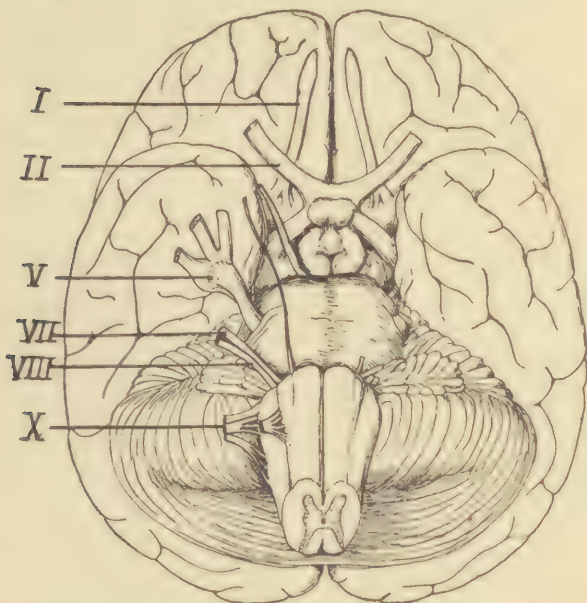


FIG. 30.—The under surface of the human brain. The manner of origin of the cranial nerves is shown more fully upon the left side of the figure (which is the right half of the brain). Roman numerals are appended to those nerves to which particular reference is made in the text.

are responsible for the sense of smell. The olfactory nerves are the farthest forward of all in the cranial series, so they are spoken of as the first cranial nerves. The second pair are the *optic nerves*, trunks of large size coming from the eyeballs to a place on the under surface of the brain where they appear to cross in the form of a letter X. Their fibers enter the brain-stem close

to the cerebrum. The remaining cranial nerves are connected with the brain-stem at short intervals between the place of entrance of the optic fibers and the opening at the base of the skull through which the spinal cord goes out.

We need not make a complete list of the cranial nerves and the regions with which they stand in relation but certain ones may be noticed. The fifth pair are the important *trigeminal* nerves, bringing in sensory fibers from the face, the outer surface of the eyeballs, the teeth, and the linings of the mouth and nose. The seventh nerves are the *facial*, controlling the small muscles on which the play of facial expression depends. The disabling of one of these nerves, or rather of the gray matter related to it, causes a drooping of one side of the face, a condition which is not uncommon. The eighth pair of cranial nerves are the *auditory*, valuable not only as mediating the sense of hearing but bearing an important part in shaping the reflexes that serve to maintain equilibrium. The tenth or *vagus* nerves, already mentioned, have a manifold service, as we shall see.

White and Gray Matter in the Brain.—The brain-stem resembles the spinal cord in having white matter at the surface. But the H-figure is not to be traced within; the gray matter occurs, rather, in more or less isolated collections. Some of these are distinctly tributary to certain cranial nerves and are described as the *nuclei* of these nerves. The cerebrum and the cerebellum have gray matter spread in a thin layer over their surface, a development called the *cortex*. We have every reason to believe that it is upon the organization of the cortex, especially of the cerebrum, that the rank of an animal depends. The human cortex is thus of extraordinary interest to us. The convolutions seem to be devices to increase the extent of cortex. The interiors of the cerebrum and the cerebellum are taken up chiefly with white matter, fibers

sweeping in all directions, but there are some submerged clumps of gray matter in both these divisions. A series of small, communicating cavities can be followed through the brain-stem and into the hemispheres. These spaces contain a clear fluid identical with that held between the layers of the meninges.

The Medulla.—To look at the medulla one would think it merely an extension of the spinal cord. But this short segment of the nervous axis has unique powers. The function which we must first recognize is the control of breathing. We say that the medulla contains the *respiratory center*. This was inferred about a hundred years ago when it was shown that cutting the cord below the skull permanently stops the breathing and so, in the case of any of the higher animals, causes immediate death. Cutting through the brain-stem just above the medulla does not stop the breathing and is, therefore, not instantly fatal. Comparing the results of these two experiments, physiologists have been led to believe that there is in the medulla an important station from which breathing is directed. Its position has been more narrowly defined by slicing across the medulla repeatedly, beginning at the top, and noting at what level the progressive destruction has abolished the breathing movements.

The muscles used in breathing are, with minor exceptions, supplied with motor nerve fibers originating in the spinal cord. Hence, the cells in the medulla must not be thought of as directly connected with these muscles but with the lower order of nerve cells in the cord. Here for the first time we have an example of what is common enough in many other mechanisms, a higher center presiding over a number of centers of lower rank, as a colonel commands the captains in his regiment. It may be added that in the respiratory system the "captains" exercise no discretionary power when their superior ceases to hold them to their work.

The respiratory center is much subject to reflexes.

Almost any sudden shock is certain to modify the breathing in some way. On the other hand we are not to think that the taking of each breath is a reflex act. It is probably accomplished without the essential assistance of afferent impulses. The center is said to be *automatic*. This is a word we have used before to describe cardiac and smooth muscle. As those two contractile tissues tend to exhibit a rhythmic type of activity in the absence of recognizable stimulation, so the respiratory center seems disposed to go on in the performance of its duty without external prompting.

When we say that automatic tissues are active in the absence of external stimuli we do not say that they are not responding to a local or internal excitation. We must suppose that they are. Chemical conditions developing moment by moment doubtless determine their behavior. Many facts bearing upon this matter have been discovered and some of them we shall have occasion to speak of in discussing the heart-beat. As regards the respiratory center the most significant point is its response to variations in the carbon dioxid content of the blood. An increased concentration of this gas in the blood carried to the brain produces a prompt increase in the breathing movements.

A diminution of the carbon dioxid in blood below the usual amount may cause a suspension of breathing. This favors the view that carbon dioxid is the normal stimulant for the respiratory center. It will be convenient to postpone a fuller treatment of this subject until the physiology of respiration is taken up.

Other services of the medulla are connected with the *regulation of the circulation*. It will be recalled that the vagus nerves spring from the medulla and these nerves contain many fibers which extend to and from the heart. Destruction of the medulla will not stop the beating of the heart as it stops the breathing but

the heart will be deprived of a certain control by the operation. The influence withdrawn is mainly of an inhibitory sort and the result is a quickening of the heart rate.

Besides exercising a regulating function upon the heart the medulla is responsible for the maintenance of the tone of the blood-vessels. This fact is expressed by saying that the medulla contains the *vasomotor center*. To destroy the region to which this name is applied is to cause a nearly universal slackening of the small arteries and veins, showing that they were previously held in a state of sustained contraction. Vasomotor reflexes can best be studied in connection with the other problems of the circulation.

The medulla is the seat of still other mechanisms, some of which pertain to the alimentary system. It has to do with the execution of swallowing, an act which is more complex than we are apt to appreciate. It is concerned in the government of the salivary glands and the glands in the lining of the stomach. And we must not forget that the medulla is also a part of the main line of communication between the higher parts of the brain and the body. It is traversed by the fibers which we employ in voluntary acts and by those which make possible the sensations which we refer to the trunk and extremities. Many of the paths of transmission which lie in the medulla cross from one side of the mid-plane to the other while passing through. This has to do with a prominent and curious truth—that the right side of the cerebrum sustains relations chiefly with the left side of the body and vice versa.

The limited portion of the brain-stem which intervenes between the medulla and the cerebrum is of interest to us as containing way-stations on the paths from the eyes and the ears to the higher centers. This part of the brain is also known to preside over the muscles which rotate the eyeballs, change the visual focus for different distances, and alter the size of the pupils.

The Cerebellum and Equilibrium.—It has been said that the cerebellum is a dorsal outgrowth from the brain-stem. It can be cut away without interrupting the direct lines by which impulses pass along the nervous axis. When the brains of different animal species are compared we find that no correspondence between the size of the cerebellum and intelligence can be established. This part of the brain is particularly large in birds and fishes. One thinks naturally of the remarkable locomotor powers of these types, the coördinated muscular system of the fish that corresponds in number of elements with the elaborate skeleton and the equipment for flying which so distinguishes the bird. There is in fact no doubt that the cerebellum stands in some relation to locomotion and balancing.

When it has been removed from a pigeon the bird presents a distressing picture. It seems quite as sensitive as a normal bird and overcome by panic. It cannot fly; if tossed into the air it falls fluttering helplessly and throws itself about on the ground. It cannot even keep its feet. No muscles appear to be paralyzed, but there is a lamentable loss of the ability to use them in groups for common ends. A bird that has undergone this operation will injure itself if it is not restrained. If it is carefully kept and tended it improves considerably, but does not recover its original poise and control.

A similar experiment has been made upon the dog. With this animal also the first impression is of utter failure to coördinate the movements. The dog rolls and writhes as though convulsed with pain. Yet it is probably not suffering unless from terror and bewilderment. After a time there is a great degree of recovery but there is a permanent unsteadiness, awkwardness, and quick susceptibility to fatigue. On the whole there seems to be no doubt that, while the earlier experimenters assigned the function of equilibration too exclusively to the cerebellum, it does have to do with

this function. This will be a good time to outline the reflex adjustments by which the balance is preserved.

A statue of a man is a most unstable object. It cannot be relied on to keep its feet when there are forces tending to upset it. But we see the living body maintaining an erect position in the midst of disturbing circumstances, bracing against the wind, adapting itself to slopes, and saving itself from falling again and again. The mind is ordinarily but little occupied with these processes; they seem to take care of themselves. To say this, is practically to say that the reflex principle is involved. We shall find that this is clearly the case.

The body is always swaying more or less. Each oscillation threatens a fall, but normally there is a timely check and reversal of the movement. If this is a reflex we must seek to show what receptors are stimulated to insure the reaction. We have to recognize several orders. The following are certainly to be included: (1) those in the soles of the feet, (2) a great number in the muscles, tendons, and joints, (3) the eyes, and (4) the internal ears. The order does not necessarily indicate their relative importance.

1. When one sways forward the pressure on the soles of the feet becomes lessened at the heels and increased at the toes. If the body tilts to the right the pressure upon that foot is increased and the weight borne by the left foot is diminished. There are receptors in the soles which are responsive to stimulation by pressure. The afferent currents which result have a long course to run to reach the brain. In the gray matter of the cerebellum, and probably in other places too, they generate efferent impulses which play upon the motor cells of the cord and secure purposeful contractions of various muscles tending to restore the balance.

2. Any swaying of the body alters the tension of many muscles and their associated connective tissues. The bearing upon one another of the small bones in the feet is subjected to change, the stresses in all the

leg and trunk muscles are modified, the weight of the head puts special and varying strain upon the muscles of the neck. We must never forget that the motor equipment of the body is at the same time a great receptor system. No muscle is contracted without registering its action by returning impulses to the cord and brain. When a muscle is stretched by an external force the same thing is true. One of the chief services of impulses thus generated is to guide the adaptive reactions that make for equilibrium.

3. If the head moves the retinal pictures are shifted. Our attention is not usually fixed upon this matter but if we attend to it at all we are quick to interpret the experience as due to the swaying of the body. Whether we realize the displacement of the images or not we may not doubt that it is one of the sources of stimulation on which we depend to steady ourselves. No one, probably, can stand quite so steadily with the eyes closed as he can when he is using them. Reliance on the eyes is more absolute when the other mechanisms are at fault; there are cases of nervous disease in which the victims reel and fall when the eyes are bandaged, though able to stand by their aid.

The giddiness and alarm which we feel when at the verge of a precipice can be explained in this connection. It is not wholly the result of imagined danger. We are used to the presence of objects in front of us and the apparent movement or parallax of these objects is a familiar condition of our life. If we are placed where the nearest rocks and trees are many yards away, before or below us, the seeming movement of these landmarks is much less than that to which we are accustomed. We miss one of the clues to our own success or non-success in keeping our poise. No doubt it is much easier to stand at the brink of a chasm 10 feet wide than on the edge of a broad abyss of the same depth. The danger of a fall is no greater in the second case than in the

first, but we are greatly sustained by the visual stimulus furnished by the opposing wall of the chasm.

4. A very remarkable mechanism contributing to equilibrium exists in the internal ear. When we mentioned the auditory nerve a short time ago we stated that this nerve does not serve solely to mediate the sense of hearing. One of its two divisions has this function; the other is valuable because of the corrective reflexes it produces when the balance is endangered. This branch of the auditory nerve is called the *vestibular*. Its fibers arise in the winding cavities of the temporal bone which constitute what is fitly termed the *labyrinth*. These cavities are filled with liquid. When the head is moved as one sways, or more violently when one stumbles, the fluid is shaken. In it are delicate filaments which appear to be connected with the nerve fibers that take their departure from the linings of the labyrinth. Thus we have in the internal ear a receptor system which is very sensitive to mechanical disturbances and sends to the brain the impulses which result.

We are not usually aware of the nerve currents that arrive in the central nervous system from the labyrinth. When we do become cognizant of them it is to feel the sensation of vertigo. It is likely that the internal ear allies itself with other receptors to induce sea-sickness when the body is persistently moved about in space by the rolling and pitching of the vessel. Of course we are much more accustomed to horizontal than to vertical movements. This fact has been used to explain the relief experienced by the victim of sea-sickness when he lies down. The motion of the ship is then brought to bear upon the portion of the labyrinth affected by familiar movements in a level plane; this system of receptors is less sensitive than its associates which have not been so often agitated. When dizziness is caused by revolving the body the disturbances of the ear receptors are combined with a

curious ocular reaction called *nystagmus*. It will be worth while to say a word about this movement.

If a person is spun around, as in an office chair, the eyes behave in a characteristic fashion. Suppose the rotation is toward the left. The eyes fix themselves upon some object and as the body is turned away from it they are swung in the opposite direction (toward the right), keeping the landmark in view as long as possible. When the eyes can be carried no farther they are snapped very sharply to the left and another object is seized upon. There is again the measured sweep to the right and the quick snap to the left. The name *nystagmus* is applied to this alternating movement of the eyes in which the travel opposite in direction to the rotation of the body is moderate in speed while the counter-movement is extremely rapid. The behavior of the eyes may be likened to that of the stop-watch, the hand of which moves from its starting-point at a rate which is easily followed, but eludes observation as it flashes back.

When the subject of such an experiment is brought to rest, the *nystagmus* continues for a time. It is accompanied by the distressing illusion that "everything is going round and round." The uncontrollable movements of the eyes continually shift the images upon the retinas. It is thought that the quick, snapping motions are not sources of sensation while the slower ones are vividly effective. The result is, accordingly, the impression that the surroundings are revolving in one direction rather than oscillating back and forth. By closing the eyes one lessens but does not entirely do away with the feeling. When the shifting images can no longer be seen there are still sensations from the eye muscles as they go on with their unprofitable working.

We are not justified in saying that the cerebellum is the only central station through which the reflexes making for equilibrium are brought about. Nevertheless, it is the most obvious of such stations and it is undoubtedly traversed constantly by impulses which have

had their rise in the eyes, the ears, and the muscular apparatus. It is as constantly sending out impulses destined to modify the action of the skeletal muscles and through them to assist in preserving equilibrium.

The Autonomic System.—This term is used to distinguish that part of the efferent nervous system transmitting impulses from the central axis to the heart, the glands, and the smooth muscle of the entire body.

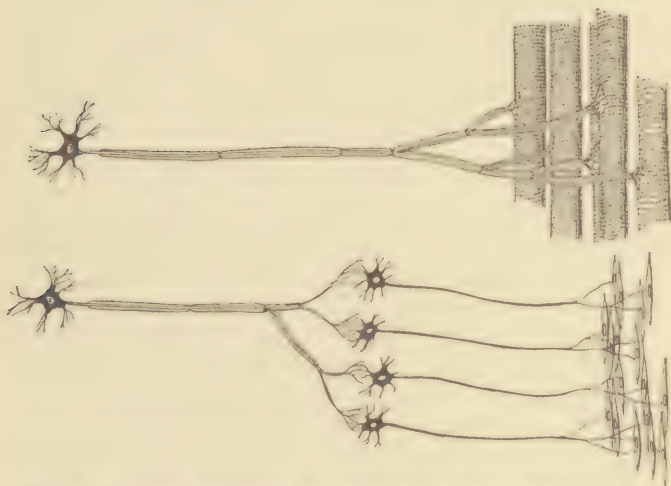


FIG. 31.—Above is shown the typical motor neuron extending from the central nervous system to the fibers of skeletal muscle.

Below is the autonomic type of path. The neuron which leaves the central nervous system does not span the whole interval but ends in synaptic union with ganglion cells. These in turn send axons to the tissue controlled—in this case smooth muscle.

The name autonomic is nearly equivalent to “self-acting” and is used to emphasize the contrast which exists between these mechanisms and the skeletal muscles—the latter being more definitely under our control. Autonomic pathways lead away from the central system at every level from the third cranial nerve to the most posterior portion of the cord.

We have seen that the paths from the brain and cord

to the skeletal muscles are represented by continuous fibers spanning the interval. In the autonomic system the case is otherwise. Fibers which issue from the brain and cord, bearing impulses destined to take effect in structures other than skeletal muscles, do not actually extend to these terminal stations. They end by synapses against nerve cells of a second order which in their turn control the effectors in question. These distributing neurons usually have their cell-bodies in various ganglia which are found in many localities. The fibers which run from the central nervous system to the way-stations are called *pre-ganglionic*, those which relay the impulses to the end-organs are called *post-ganglionic*. It appears to be the rule that one pre-ganglionic neuron stands in relation to a number of those of the dependent rank. It seems to follow that impulses sent from the brain and the cord to the ganglia are there multiplied and diffused. There can hardly be the precise localizing of effect obtainable in the command of skeletal muscles.

The pre-ganglionic fibers proceeding from the spinal cord are for the most part connected with ganglia which are placed in two long chains to the right and left of the spinal column at the back of the body cavity. These two chains of ganglia with their associated axons have been known as the *sympathetic system*. The term is an odd one and is not to be given any tinge of the psychologic significance naturally coupled with it.

The functions of the autonomic system may be summarized under three divisions: First we have those of the head or cranial section. Fibers originating here produce effects in many organs of the trunk as well as in the head. They can bring about contraction of the pupil, increase of curvature of the crystalline lens, changes in the circulation in the glands and skin of the head, secretion of saliva, and slowing of the heart. They also contract the bronchial tubes, cause the secretion of gastric juice, and reinforce the muscular activity of most of the alimentary canal.

The second (thoracico-lumbar) division comprises all the autonomic paths leading from the spinal cord excepting a small group at its lower end. They serve to promote the contraction of most of the blood-vessels, are capable of suspending the activity of the alimentary canal, cause secretion of sweat, erection of the hairs (or goose-flesh in the human subject), dilation of the pupil, and a special activity of the adrenal bodies to be referred to elsewhere. They accelerate the heart. In the case of this organ, the alimentary tract, and the iris they definitely oppose the cranial autonomic.

The small group of paths remaining below (sacral autonomic) play upon the rectum, bladder, and reproductive organs.

Many functions of the lower parts of the brain which have been only hinted at in this chapter will receive more attention later. It remains in the present treatment of the nervous system to consider the significance of the cerebrum.

CHAPTER IX

THE BRAIN (Continued)—THE CEREBRUM

The importance of the cerebrum to the capacities of animals for reaction varies within the widest limits. We shall find that in ourselves it is without question the supreme division of the brain. As we descend in the scale of vertebrate life its place is less and less impressive until in the fish it serves chiefly to connect the organs of smell with the brain-stem. This seems a trifling function but it is one which the cerebrum in all cases fulfils. The cerebrum cannot be removed for purposes of experiment without isolating and rendering useless the receptors of the nose. (We have seen already that none of the cranial nerves beside the olfactory connect directly with the cerebrum.)

Decerebrate Animals.—An animal from which the cerebrum has been removed is termed *decerebrate*. From its behavior we can arrive at conclusions regarding the extent to which the cerebrum figures in the life-processes of any particular species. The operation is a simple one in the cold-blooded types but becomes increasingly difficult in the higher forms. It has been successfully performed upon birds and even dogs.

Fish are but little affected by the loss of this part of the brain. They are reported to behave so nearly like their mates that it is not possible to identify the decerebrate fishes among normal ones in an aquarium. They show the same preferences for certain foods that were demonstrated before the trial. A few kinds of fish—among them, sharks—are said to become notably inert, but close observation has shown that this is owing to the loss of the olfactory organs on which they evidently depend to an exceptional degree.

Decerebrate frogs would pass for perfect animals if the inspection were not quite patient and conscientious. Those who have studied them most closely tell us that they are rather more machine-like or less "spontaneous" than intact frogs. They are liable to blunder against obstacles and they will not surely save themselves from death when gradually heated in a pan of water. This is in spite of the fact that they jump with vigor when stimulated in other ways. It is claimed that a frog which has learned anything—how to escape from a certain enclosure, perhaps—will lose the accomplishment when decerebrated. If this is correct it is of the utmost interest for it foreshadows the special property of the cerebrum higher in the scale.

Those animals which we feel warranted in calling "lower" are admirable mechanisms to work under fixed conditions. What they lack is the power to profit by experience. We cannot say that this is absolutely wanting in the simplest forms but it is more and more evident as we consider those of higher rank. In precisely the same proportion the cerebrum becomes dominant in the nervous system. The power to profit by experience, to learn, or to acquire new reactions is nearly akin to memory. The statement that the cerebrum is the organ of associative memory can be strongly defended.

The word memory is likely to suggest to the student conscious recollection. It is quite as correct to use it objectively. In this sense the memory of an impression is a modification of the nervous system manifested through the fact that reactions subsequent to the event are different from what they would be if it had never occurred. A cat when left alone in a room where there is meat on the table is likely to jump up and steal it. After certain punishments the animal may refrain from taking the food. We may say that the cat remembers the blows, or we may exclude all subjective ideas and say that the nervous system has been so changed that it does not react as it did at first. This

latter statement is not to be challenged; it is safer than the former which really rests on our imagining ourselves in the place of the cat.

We feel very skeptical regarding the possibility of disciplining an ant so that it will not approach a lump of sugar. The fact that a cat can be trained as described while an ant probably cannot, shows just what is meant by the "high" as contrasted with the "low" type of nervous system. Wonderful as the community life of ants and bees appears to us, it is an inflexible life in which there is but slight differentiation of individuals. An ant which has passed through the several stages of development enters into the life of the colony with a certain standard equipment for the part it is to play. It probably adds scarcely anything to this initial equipment as a result of its contacts, failures, and successes. It does not come to have any individuality that the human observer can discover. Dogs and cats, on the contrary, have plastic nervous systems which are affected by countless impressions and endow these animals with well-marked personalities.

To remove the cerebrum is to rob an animal of what it has acquired in living its own life. What remains is the common heritage of the race. This is borne out by the classic experiments upon the pigeon. Early in the last century the condition of this bird after decerebration was carefully described. Many repetitions of the operation have modified the original conclusions in some details but have not shaken their principal lessons. The decerebrate pigeon retains striking reflex capacities but can hardly be thought of as a sentient or teachable being.

The bird is most of the time in an inert state suggestive of dozing. It can be roused by positive stimulation and reacts well but quickly subsides once more. For example, if it is tossed into the air it will fly for a short distance. The direction of its flight is probably a matter of chance but it will avoid obstacles and may

swerve toward a perch. Having alighted it sinks into its customary moping attitude. Loud sounds cause it to stir, but sluggishly. It will not find food for itself though it may be within easy reach. It does not respond to the presence of its own kind nor is it disturbed by the approach of its natural enemies. Associative memory is gone and little or no power to form fresh associations is left.

The removal of the cerebrum from a mammal was long supposed to be impossible. It was triumphantly accomplished about twenty-five years ago and the feat has been repeated many times. In the first successful decerebration of a dog the brain substance was cautiously washed from the cavity of the skull, the process being completed in three stages with long intervals to permit recovery from the shock. The dog rallied well and was kept in fair condition for more than a year, though toward the last its strength was failing. It was finally killed and the autopsy showed that cerebrum had been wholly obliterated.

This dog gave the same general impression which one derives from watching a decerebrate pigeon. The animal was mechanically competent but idiotic. It roved about the laboratory, making detours around objects in its path and taking the same pains to avoid patches of sunlight on the floor. It chewed and swallowed food which was brought to its mouth but did not seek it. It would snap at the hand of anyone who pinched it but only during the irritation; it did not conceive of such a one as an enemy, and harbored no prejudice against him. It was questionable whether it ever learned anything by experience after the operations.

The human cerebrum is very large in proportion to the rest of the nervous system and to the total mass of the body. This coincides with the evident fact that man has less inherited power of coördinated action than most of the lower animals and far more capacity to develop reactions based on memory. We do not make deliberate experiments upon the human brain, but nature

makes many which are at once deplorable and instructive. We are often compelled to see the havoc wrought by hemorrhages, tumors, and other agencies which injure the intricate mechanisms of the cerebrum. On the whole, the collected data confirm the belief that we have here the physical apparatus of intelligence.

In all probability the human cerebrum, besides representing an advanced type of outfit for recording individual happenings, has taken over certain functions which in the dog are subserved by other parts of the brain. We have noted the use of the eyes in maintaining equilibrium. As a rule this is a subconscious service and we have seen that in the decerebrate pigeon as well as in the dog it continues in the absence of a cerebrum. It is not likely that it could so continue in man. When certain local damage is suffered by the human cerebrum there is total blindness so far as can be determined; no subconscious guidance in locomotion is afforded by the eyes.

Quite recently there was published a description of a defective child that lived four years before it was happily released by disease. It was found postmortem to have no cerebrum at all, the space being filled with fluid. There had been no appreciable progress in acquiring new reactions from the day of birth. The child seemed blind and generally lay passive as though sleeping. No certain token of consciousness had been recognized. This dreadful case lends weight to the usual view: that all individual gains in adjustment to the environment are conditioned by the organization of the cerebrum.

Localization.—Granting that intelligent activities have their physical accompaniments in the cerebrum, what can be said of the distribution of these processes? This has proved a fascinating and difficult question. For more than a century it has been before physiologists and physicians. In 1830 the belief in precise localization of function was very widespread, by 1860 it had been replaced by skepticism in regard to any such topography.

In 1890 a new doctrine of localization, almost unrelated to the old, had gained general acceptance. At present there is another reaction; the tone of most writers is cautious and conservative. We can deal only very briefly with these pendular movements of scientific thought.

The old teaching is remembered under the name of

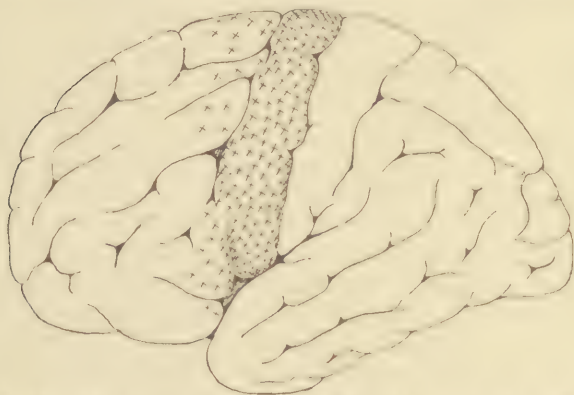


FIG. 32.—The human cerebrum is sketched from the left side. The crosses are sprinkled on the area from which the muscles of the right half of the body appear to be governed. This area extends out of sight over the top of the brain and dips into the fissure between the two hemispheres.

Phrenology. The early advocates of localization busied themselves with attempts to correlate the character and accomplishments of men with the forms of their heads, assuming rather rashly that the shape of the brain can be accurately judged from the contours of the skull. They came to believe that numerous subdivisions of the cerebrum must exist, each standing for a mental characteristic. The idea is that of so-called "bumps." Phrenologic diagrams show how far their makers believed the analysis could be carried. The inferences drawn became more and more far-fetched until the school fell wholly into disrepute.

The conception of a cerebrum having its surface

plotted in little areas concerned with specific functions gave way for a time to the view that there is no distinction between the duties of its different parts. It was compared with the liver, a large organ having several simultaneous activities. A particular lobe of the liver is not supposed to have a single service but rather to participate in all the work of the organ as a whole. So it came to be thought of the brain that cerebral functions are not local but diffuse. To destroy a part, it was held, would not suppress any one power but would weaken all.

When new evidence of localization in the cerebrum began to be obtained the emphasis was quite different from that which had prevailed in the days of phrenology. Less was said of the correlation of brain and mind and more of the correlation of brain and body. The first special areas to be defined were those which we call motor, regions of the cortex which appear to have a closer connection with the skeletal muscles than can be claimed for other portions.

The Motor Areas.—These are distinguished by the fact that electric stimulation applied anywhere within their boundaries causes movements of various parts of the body. The muscular responses occur chiefly on the opposite side as already implied. The motor areas have been carefully mapped for the cat, the dog, and the ape. In the last-named animal the general appearance of the brain is very like the human and there is no doubt that in the cerebrum of man there are motor areas in a corresponding position. A diagram will show how they are placed. Cerebral localities are referred to under the names of the bones of the skull which lie over them and these areas are said to be in the frontal region along the border of the parietal. Roughly, they may be said to extend upward from the ear to the top of the head.

Microscopic study of the brain shows that the surface gray matter of the motor regions contains many large nerve cells, of a type called pyramidal, from which the axons of nerve cells pass inward. The fibers which

thus have their origin in the motor areas become condensed into well-defined bundles which can be recognized at each successive level in the brain-stem. In the medulla most of these fibers sweep across into the opposite half of the nervous system and descend the spinal cord to connect with the motor cells in its gray core. It will be noted that a fiber from the cortex never reaches a muscle; it plays upon a cluster of cells of a lower order and the contractile elements are governed by these. Something like this has been seen to be true of the respiratory center in the medulla.

When the motor areas in man are extensively damaged, or when the fibers carrying impulses down the axis from these areas are interrupted, a disabling paralysis results. This is to be contrasted with the coördinating powers of the dog which can lose not merely the motor regions of the cerebrum but the whole of that division and still balance and walk. We have here another illustration of the concentration of functions in the cerebrum of the higher forms and the reduction of capacity in the cord and brain-stem.

Movements which we call voluntary are assumed to be preceded by processes in the cerebral motor areas. In all probability this is equally true of many movements which we class as involuntary. The line of demarcation is arbitrary and of little value. Even when an act is as clearly as possible deliberate we cannot say that the process originated here or there in the cerebrum. The excitation of a motor spot is presumably to be referred to some other part of the brain and as we attempt to trace the action to its source we are baffled and left unsatisfied. We are forced toward the conclusion that the ultimate cause of every movement is to be sought on the afferent side of the nervous system. But we rebel vigorously at the suggestion that there is no such thing as choice or freedom.

A review of the facts we have accumulated will convince one that the skeletal muscles are put to work now through lower and now through higher nervous mechanisms. A

man stands at a counter in a bank, writing a check. His regular breathing we refer to activities localized in the medulla. The maintenance of his posture depends upon complex reactions mediated in part by the cerebellum. The writing approaches a purely cerebral performance.

Sensory Areas.—As the motor regions of the cerebrum are regarded as places from which impulses take their departure to affect subordinate mechanisms, so there are in the cortex areas within which sensory cur-

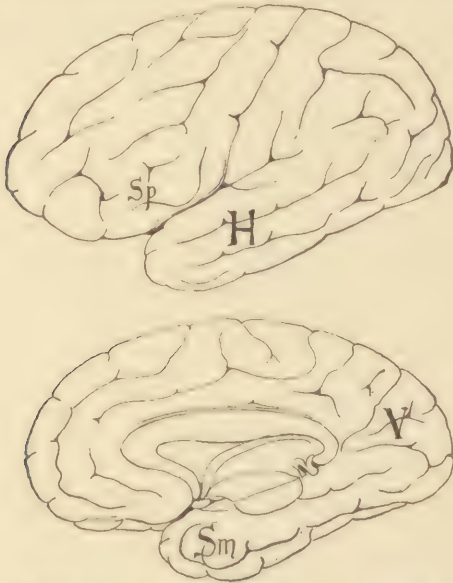


FIG. 33.—The upper figure represents the left hemisphere from outside, that is, from the left. The lower figure shows the internal or mesial aspect of the *right* hemisphere from the left side. Areas usually claimed to possess special relations are marked as follows: *H*, hearing; *V*, vision; *Sm*, smell; *Sp*, speech.

rents are received. As the cells of the cerebrum never connect directly with the fibers of skeletal muscle, so the receptors of the body never connect directly with the cortex. At least one relay is made on each sensory path and usually more than one. We are best ac-

quainted with the relations between the eyes and the brain.

Each retina is a cup-shaped structure functionally subdivided like a mosaic into a vast number of minute areas, every one having its own connection with the optic nerve. The fibers of the optic nerves can be followed, as we have seen, into the part of the brain-stem which is just below the cerebrum. There they come into relation with nerve cells through which reflexes can be produced and with other cells which transmit impulses to the cerebrum. It is not supposed that any intelligent use of the visual power can be based on the employment of the brain-stem by itself. We believe that the cerebrum must be involved.

The part of the cortex to which the impulses of visual origin are first sent is as far from the eyes as possible, the rear or occipital region of the cerebrum. The area most certainly used is a portion of the surface where the right and left hemispheres are in contact, the sides of the deep cleft which is between them. Injuries here have caused blindness in many subjects. We know that the central part of the retina has superior usefulness in seeing and it is probable that its connections are correspondingly extensive. When sight is recovered after its temporary loss through pressure on the visual cortex, the patient may at first see only in a very small central field and this may gradually widen as the improvement continues.

After learning of the crossed relation between the cerebrum and the muscles one may expect to hear that the right eye is connected with the left side of the brain. The actual arrangement is less simple. The *right half* of the *right* retina, approximately, and the *right half* of the *left* retina also, have relations with the right side of the brain. The images on the right halves of the retinas are those of objects toward the left of the observer. It follows that destruction of the visual cortex on the right side of the cerebrum will result in loss of vision in the left half of the field. Strictly speaking,

it is said that the loss in such cases is a little less than half, the central element being preserved entire instead of being cut through on a meridian. This is interpreted as signifying a reduplication of the representa-

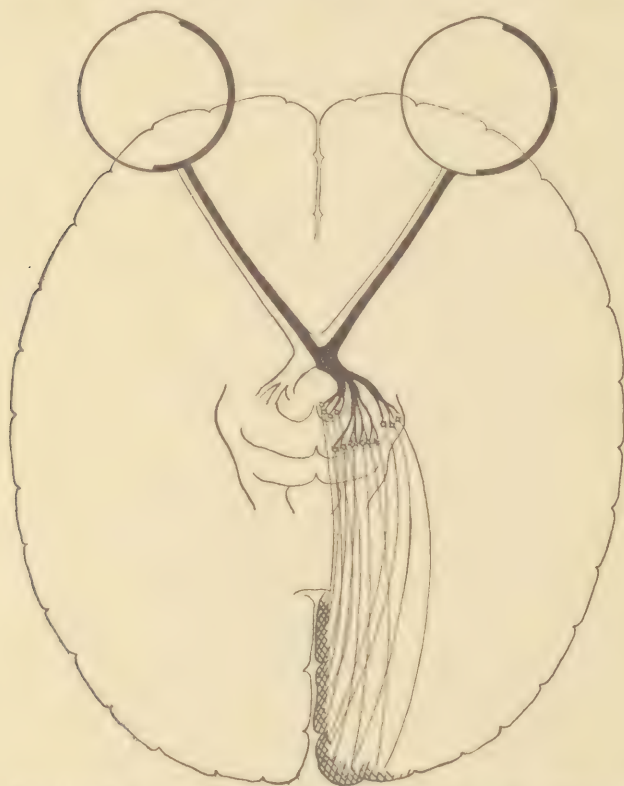


FIG. 34. The relation between the retinas and the brain. The right half of each retina is heavily scored and will be seen to be connected with the right occipital region through intermediate centers.

tion of this superior central area in the two occipital regions.

Impulses arriving from the part of the ear which has to do with hearing traverse the medulla and ascend

by relays through the remaining portion of the brain-stem, reaching the cortex at last in what is called the temporal lobe. The majority of impulses from the right ear are said to be brought to the cortex on the opposite side although a fraction seem to reach the station on the side of their origin. Impulses from the nose, adapted to cause sensations of smell, are distributed near their point of entrance into the cerebrum on its under surface. There is some uncertainty as to the cerebral localization of taste. Behind the motor areas in the ape, and probably in man, there are strips of the cortex within which many sensory impulses from the body in general seem to be focused.

Association Areas.—As we have pictured the cerebrum it has, on each side, several areas of a receptive function and one well-marked area from which impulses take their departure to initiate movements. If an animal is to behave in a normal manner, that is, to be guided by its circumstances in what it does, there must be connecting links between the receptive and the discharging stations. The higher the organization the more devious and difficult to trace are these connecting links. There may be short cuts between sensory and motor regions insuring certain reactions of a reflex type but many of the ways of communication are most indirect. It is supposed that they are made by intermediate portions of the cortex to which we give the name of the association areas. These are not united by fibers with the brain-stem but only with each other and with the sensory and motor fields. Fibers which run between the cortex and the brain-stem or cord are called *projection fibers*; they connect higher with lower, or lower with higher, levels. Fibers which run from point to point in the cortex are called *association fibers*. According to these definitions the association areas have no projection fibers.

It is natural to consider the association centers as the highest of all in the character of their service. They

are farther removed from both muscles and sense-organs. They are known to be late in their development. The more extended and subject to change the paths from simple sensory to primitive motor centers the more variation we may expect to observe in the conduct of an animal—the more spontaneous and the less machine-like it will appear. Every such path is supposed to lie through association areas. In the striking out of these paths there is the greatest possibility for individual divergence.

In the human brain one of the great association areas lies in the frontal region and another in the parietal. There are doubtless many other parts of the cortex, of less extent than these, which have the same characteristic: that is, absence of direct connection with the brain-stem. Disease, when limited to such parts of the cortex, does not produce clear and definite symptoms, like paralysis, blindness, or deafness. It is more likely to result in indefinite but serious loss of intelligence. Sometimes we hear of a wonderful preservation of all the faculties in spite of gross injuries by gunshot wounds or otherwise. When we consider the fatal effects commonly following brain injuries we must bear in mind that, when the skull is penetrated, pressure and displacements of tissue may occur at some distance from the apparent seat of the damage.

When we compare ourselves with the lower animals we are apt to think most of our psychic life. Beyond question we are right in doing so but the physiologist, anxious to keep objective standards so far as he may, will say that we are distinguished by our *varied reactions*. The brain of man is adapted to execute these responses, to blend them, and also to suppress certain ones in favor of others. This last is a function of the utmost significance.

Cerebral Inhibition.—If we reflect a little upon what constitutes strength of character we realize that the man we admire does not do various things which a

weaker and less disciplined individual would do. We say that he exhibits self-control. He does not fly into a passion on moderate provocation; he does not quail when in danger. How shall we express these facts in the language of physiology? We shall probably choose to say that primitive reflexes have been displaced by reactions more recently acquired. The dominant reactions are those for which the indirect paths by way of the association areas are necessary. We say that the more elementary tendencies are inhibited. This is an obvious principle in matters of good breeding as well as virtue. While it is eminently a feature of human life it is not wholly wanting in the animals that we feel to be real comrades. It is signally displayed by the dog that refrains from biting the child that torments it.

Language.—One of the most remarkable of human powers is that of uttering and comprehending words. A baby is guided by spoken words much earlier than is commonly supposed and long before it reproduces the words that it hears. In course of time it learns to talk. Later the child is taught to read and to write, additional modes of making use of language. When the nervous system is fully developed, every spoken or written word is a stimulus with a definite power to affect it and to secure reactions from it. Brain disease often perverts or abolishes the use of language. Sometimes it is the ability to speak that is interfered with, sometimes the capacity to act under the guidance of words spoken by others. In the latter case we say that the patient does not “understand” what he hears. This is a psychology inference; what we are sure of is that his conduct is not determined by it.

There is a small region in the frontal lobe, on the left side in most of the subjects studied, which is reputed to be a *speech center*. It is close to the part of the general motor area from which the muscles of the vocal organs are supplied. It will be noted that these muscles are not used exclusively in speech. They are employed

in mastication, swallowing, coughing, and many other acts. They are also contracted when simple animal outcries are made. The power of speech is much more than the power to command these muscles; it is the power to make them express thought. When the alleged center suffers from local impairment through disease the disorder which results is not a paralysis but a loss of the ability to make thought vocal. This is what we mean by *motor aphasia*.

Of course all the evidence that can be gathered for the existence of a speech center is based upon post-mortem discoveries of abnormal conditions at this place when disorders of language have developed during life. The correlation of disease with loss of coherent speech has indicated that in left-handed persons the control of speech is dependent on the *right* half of the brain, that is, on the side which also presides over the skilled hand. So in the average individual who is right-handed the mechanisms for speech and for the more competent hand are again associated but on the left side. Claims for the existence of centers for reading and writing and for the interpretation of words heard have been strongly urged. Further detail would be out of place in a book of this size.

Summary.—The cerebrum, like other parts of the brain, is a place where impulses are received and so applied as to cause other impulses to be sent out. But, far beyond any other division, it is influenced by the passage of impulses through it. It is not so much organized by inheritance as by experience. Its capacities at birth are potential; the manner of their realization cannot be foretold. In old age it has registered the story of a life; it is the material basis of memory and so of every individual attainment. The suggestions relating to personal hygiene will be given a place in another chapter.

CHAPTER X

SENSATIONS AND THE SENSE-ORGANS

We have spoken in a general way of the receptors of the body as sources of nerve-impulses which are conveyed to the central nervous system and bring about reflexes which, as a rule, are clearly valuable to the organism. Now we must give some attention to the states of our consciousness which apparently result from the stimulation of receptors. Our subject is that of the sensations and it is one common to physiology and psychology.

We cannot take up this matter from a metaphysical standpoint. On the physical side a sensation is the accompaniment of a certain process in the brain which we usually assume to have been induced by external forces acting upon the receptors. One of the very first things to be insisted upon is that sensations may be experienced when the external stimuli are absent, provided the brain process takes place. This is often the case, we may suppose, in our dreams. Sensations that do not have any external cause demonstrable to other people are called *hallucinations*. The more one studies the nervous system the more the wonder grows that we are not often deceived in regard to the origin of our sensory experiences.

A question that has to be dealt with at the outset is whether or not nerve-impulses are all alike. It is plain that they are most unlike in their effects. Those that go to the skeletal muscles throw them into contraction, others running to the glands set them to secreting, still others led to the heart may restrain it from beating. On the afferent side the impulses that enter the brain

by the optic pathway give rise to visual sensation, while those from the upper part of the nose are responsible for olfactory impressions. One would be inclined to say that the impulses must be of the most widely varied character. It is, therefore, a surprise to the student to hear that most physiologists have adhered to the view that they are essentially uniform in all nerves.

How can we account for the facts before us without admitting that the impulses can differ in kind? It should be said frankly that this may be impossible, but we always prefer a simpler conception to one which is more involved unless we are compelled to adopt the latter. If nerve-impulses are all alike, our emphasis must be upon the places to which they go rather than upon the currents themselves. We shall find that there are analogies to help us in the attempt to do this.

The lighting of a gas jet and the ringing of a bell are, perhaps, as different as the movement of a muscle and the act of secretion performed by a gland. Both may be caused by electric currents produced in similar batteries but led through different and suitable fixtures. No one would argue that the current used to light the gas had any specific gas-lighting virtue in itself; it could as well do something else. This is parallel with what is known as the Müllerian doctrine in regard to the nervous system: that nerve-impulses vary only in intensity—not in kind—and that they produce one effect or another according to the particular structures on which they finally act.

The impulses in the fibers of the optic nerve have been assumed to be of the same order as those in the auditory. Upon this assumption it has been suggested that if impulses having their origin in the retina under the influence of light could be switched over into the path from the organ of hearing and so arrive at the hearing centers of the cerebrum anything ordinarily visible would be audible; one could listen to lights and colors. There is another consequence of the Müllerian principle



FIG. 35.—The "crazy bone." The ulnar nerve is exposed to rather frequent shocks near the point of the elbow (c). Impulses running up to the brain as a result of such accidents produce sensory effects which are much the same as though they had traversed the whole length of the fibers from their receptors in the shaded region of the hand.

that is more easily tested. If impulses are always the same then, no matter what means may have been employed to start them, invariable effects will be produced by the stimulation of a selected path. If all the fibers in the optic nerve have such connections with the brain as to arouse sensations of light then we may excite the optic nerve in an unusual way and still obtain the only kind of sensation proper to this collection of fibers. This seems to be very nearly true.

We have testimony to the fact that cutting this great nerve does not give pain but the sensation of a bright flash. Pressure on the eyeball will produce spots or circles of color. If it is objected that there is also the sense of pressure it can be replied that a different nerve from the optic is known to be concerned in this reaction. Electric stimulation of the endings of the olfactory nerve is said to cause an odor.

One result of the alleged uniformity of nerve-impulses is that we have no way to tell whether they come from the distant endings of a nerve or from some point intermediate between these endings and the centers. This is simply illustrated by the common mishap of striking the elbow a sharp rap. The nerve that passes over the bone at that joint is mechanically excited and the impulses which ascend it have the same effect as though they had come all the way from the fingers. We say that the *fingers* tingle because we are more used to sensations caused through

the whole length of the fibers from their receptors in the shaded region

their receptors than to those produced by the abnormal method.

A closely related experience is that of the victim of an amputation. He describes minutely pains and other feelings which seem to come from the lost limb. We have only to reflect that all the fibers which formerly conducted impulses from the missing part are still present in the stump and if they are stimulated by reason of temporary conditions there they will give rise to the old, familiar sensations. The engineer of a steamboat cannot tell whether his gong has been rung from the pilot house or from some other station. We are usually saved from confusion by an important property of the afferent system: that nerve fibers are much more resistant to stimulation along their course than at their specialized receptive terminations.

The Classification of Sensations.—The five senses ordinarily recognized do not satisfy the requirements of an inclusive enumeration. They are all of the class which the physiologist calls special. He sets over against them another group, the common or general sensations, in which he places those which seem to have their causation within the body. Special sensations are those referred to the external world. Examples of common sensations are hunger, thirst, fatigue, nausea, and many kinds of pain. One is struck with the prominence of disagreeable feelings in this class and this may be connected with the fact that they usually stand for conditions that call for readjustment. Because these sensations are unpleasant we are prompted to take measures for their abatement and the interest of the organism is served.

There are some sensations which lie on the border line between the general and the special orders. In explaining how the equilibrium is preserved we mentioned the afferent impulses from the musculature. These are mostly applied subconsciously to produce appropriate reflexes but this is not the whole story.

They have to do with those sensations which are called *kinesthetic*, those feelings which we have respecting our posture, and our ability to realize our own movements. One need not look at the extremities to see how they are disposed; there is sensory evidence of one's position at all times.

Our *temperature sensations*, also, lie in a class intermediate between the varieties which are clearly special and those which are necessarily general. If a small object touches the skin we say that the object is hot or cold; we do not consider that the patch of skin has taken the temperature of the thing in contact with it. But if the whole surface of the body is warmer than usual we may say either that the room is warm or that we are.

Under the head of special sensations we have those produced by the stimulation of the skin and those pertaining to taste, smell, hearing, and vision. In other words, these are the five senses with the qualification that what is called touch is multiple. It is to be resolved into pressure, warmth, cold, and probably surface pain. Surprise may be expressed that warmth and cold should be separately mentioned. But we have pointed out elsewhere that the physical conception, according to which cold is merely less heat, cannot be applied to such a system as this. Cold stimulates nerve-endings as truly as does warmth and with equally positive results.

If all nerve-impulses are alike how can we explain the three or four distinct sensory capacities of the skin? There is only one resort—to assume that there are as many separate sets of receptors as there are sensory qualities. This is the usual belief. Close study of the responses to be obtained from the skin has shown that there are minute areas which are capable of furnishing one sensation and no more. Thus there are pressure points, warm points, cold points, and pain points, according to the standard description. An area with one

and only one sensory property presumably has just beneath it a receptor for one kind of stimulation. The capacity for sensation which we can demonstrate for the skin holds with minor differences for the lining of the mouth. In the esophagus we have a persistence of the response to temperature changes but a practical loss of the other feelings.

Liminal Distance.—A general idea of the relative refinement of the pressure sense in various parts of the body may be secured by finding how far apart two blunt points must be placed so that when they are applied to the skin they shall be felt as two rather than one. The interval necessary for any part of the surface of the body is called the *liminal distance*. It is least on the tip of the tongue where two points need be separated by only $\frac{1}{25}$ inch to be felt distinctly. The distance is about twice as great on the finger tips. This explains why a cavity in a tooth feels much larger when the tongue is pressed into it than when it is examined with the finger. Some portions of the skin are incredibly deficient in discrimination; on the back it may be necessary to touch points 2 inches apart to have their separate nature apparent to the subject.

Taste.—The receptors for this sense are mostly on the tongue. They are stimulated by many substances which must be in solution to have an effect. There are probably but four distinct kinds of taste: sweet, sour, bitter, and salt. The countless other qualities which we detect in our food are compounded of odors, contacts, temperature impressions, and in some cases an element of irritation verging on pain. There are probably four sets of fibers leading from the tongue to the brain and their endings have a somewhat characteristic distribution.

Sweet substances are most stimulating to the tip of the tongue. (Observe the happy child boring into the interior of a bonbon with that part of the little member). Salt affects rather strongly the edges of the tongue and

anything which is at all bitter is doubly so when it passes over the root at the moment of swallowing. The acid appreciation is more nearly uniform in different places.

It has been proved that taste, or a sense closely akin to it, is mediated by receptors in the skin of certain fishes. A bit of food held near, but not touching the skin of a catfish, far back toward the tail, may cause the animal to whirl about and seize the morsel. In view of the fact that taste is a sense wrought upon by matters in solution it is not surprising that an animal living in a liquid medium should have this sense represented upon other surfaces than that of the mouth cavity.

Smell.—When we pass from taste to smell we recognize that we have taken an important step. Taste, like the sensations which can be evoked through the receptors of the skin, requires the actual contact of the stimulating substance. This may be true of smell also in the sense that portions of the odorous material must be brought to the nerve-endings high in the nose, but our reference or *projection* in this case is to distant sources of the radiation. When one stands at the edge of a pond and enjoys the fragrance of the waterlilies one does not think that some portion of the flowers is in the nose. On the other hand, when a crystal of salt is tasted one does not refer the sensation to the contents of the box from which the sample has been taken. The difference in the mental attitude is very interesting.

Endeavors to classify odors have not been particularly successful. The number of types seems large, and different judges can hardly agree as to the distinctions. In fact it is much more difficult to establish an ordered system in the realm of smell than it is has been for any of the other senses. In discussing sound we have the standard of pitch and in describing visual sensations we have the spectrum. Odors, however, do not readily fall into any such continuous series.

Man is said to be deficient in the acuteness of the

sense of smell, lagging far behind many of the animals with their power to trail their mates and their prey. It can be shown by microscopic study that in such animals the olfactory nerves have notably extended connections within the cerebrum. Still it is probably true that the human endowment is superior in some respects. We can appreciate more varieties of so-called flavor (really odor) than cats and dogs can discriminate. We do not seem to be able to discover a weak odor in the presence of a strong one. A dog tracking a rabbit through a growth of sweet fern seems to do just this thing. Yet it may be that the odor of the rabbit is stronger for the dog than the fragrance of the herbage.

All sensations diminish more or less if the exciting stimuli are long continued. This kind of fatigue is marked in the case of smell. Most odors cease to be perceptible if the substance responsible remains with us. People who have been for some time in a room which has become close, or where vegetables are being cooked, may not notice odors which are very apparent to a newcomer. Our judgment as to whether odors are good or bad is closely linked with our theories of their origin. An aroma which might be thought appetizing when proceeding from a cheese would decisively condemn an egg.

Attention may be called to the probable influence of the erect position upon the relative importance of the sense-organs. An animal roving about with its nose close to the earth is in a stratum of air laden with odors. These rapidly diminish in variety and intensity with elevation. The human nose is carried at such a height that there are comparatively few sources of stimulation for it. But the same lifting of the head above the ground has somewhat extended the range of hearing and vastly widened that of vision.

Hearing.—It has been said that when we taste anything we realize its close contact with a special part of the body surface. When we smell anything there is

also a contact between some of the material and our receptors, but our thought is of the main mass of the substance which may be far away. Hearing and vision are distinguished from the other senses and superior to them in that it is not matter but *energy* which comes to us from the sources of stimulation. The ear and the eye are called *distance receptors*. Through them our universe becomes greatly enlarged.



FIG. 36.—Semi-diagrammatic section through the right ear; *G*, external auditory meatus; *T*, membrana tympani; *P*, tympanic cavity; *o*, fenestra ovalis; *r*, fenestra rotunda; *B*, semicircular canal; *S*, cochlea; *Vt*, scala vestibuli; *Pt*, scala tympani; *E*, Eustachian tube. (Czermak.)

We have seen that the mechanisms of the internal ear are useful to a great degree in connection with the maintenance of equilibrium. In some animals this is probably their essential function. It is not hard to see that organs sensitive to displacements of the body as a whole might also become responsive to the slight and repeated shocks which we call sound waves. In the higher forms, including ourselves, there is a definite division of the labyrinth to provide for the two services.

The part specialized for the translation of sound waves into nerve-impulses is a spiral passage called the *cochlea*.

Anatomists distinguish the external, the middle, and the internal ear. The external ear includes the visible part and the short passage that is terminated by the *tympanic membrane*. This is what is commonly called the eardrum, though it is strictly the drumhead. The drum, regarded as a box, is represented by an irregular cavity called the *middle ear* or *tympanum* in the temporal bone. This contains air. Communication with the exterior is by way of the *Eustachian tube* which, on either side, leads from the tympanum to the upper part of the throat or, as one may say with equal correctness, to the back of the nose.

The Eustachian tubes are very narrow; in fact they are usually closed by the contact of their lining surfaces. At certain moments, as when we swallow or blow the nose, there is an effective connection. In order that the tympanic membrane shall be free to vibrate normally the pressures on its two sides must be equal. The pressure on the outside is that of the atmosphere and subject to barometric changes. The tympanum holds a small, isolated sample of the atmosphere and the occasional opening of the Eustachian tube is necessary to the standardizing of this sample. If the channel of communication is blocked for any length of time an inequality of pressure upon the two sides of the membrane may be expected. It will be attended by the "stuffy" sensation familiar in bad colds. When the tubes are opened after long obstruction there is a noticeable snap and a marked relief.

Many persons whose Eustachian tubes do not open readily may notice the resulting discomfort when rapidly changing altitude, for example, in the ascent of a long railroad grade. As the height is gained there is a lower barometric pressure and the confined air in the tympanum is more dense than that outside. There must be, under these circumstances, a slight outward bulging

of the tympanic membrane. The ear is functioning as an aneroid barometer.

The tympanic membrane is adapted to vibrate freely in response to a wide range of vibrations in the air which comes into contact with it. It is much more serviceable than it could be if it had a strong tendency to take up a fixed rate of tremor. In other words, it has little

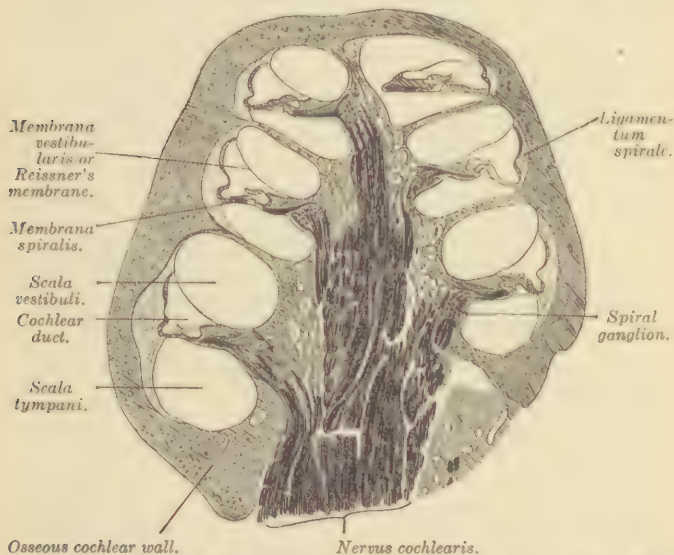


FIG. 37.—Longitudinal section of the cochlea of a cat. This figure gives a general view of the cochlea. The cochlear duct is met with six times in the section. (Sobotta.)

resonance. Attached to the membrane on its inner surface is a minute bone or *ossicle* which must vibrate with it. This ossicle transmits its motion to a second and this, in turn, to a third. The three articulated bones convey the vibrations, without altering their frequency, across the tympanum and to the beginning of the internal ear.

The third ossicle is fitted into an opening which is

regarded as the entrance to the labyrinth. The bone is smaller than the opening and the closure is completed by a pliable membrane which plays in and out with the excursions of the ossicle. Beyond this point there is no more air. The vibrations are now represented by the pulsations of a clear fluid, the *perilymph*. All the numerous and intricate structures within the labyrinth may conceivably be affected by the vibrations introduced into the perilymph from the ossicles but, as has been said, the cochlea is the organ vitally concerned in hearing.

In a clean dry skull the cochlea is a twisted passage suggestive of the interior of a snail shell, though on a small scale. It makes two and a half turns and its diameter diminishes toward the blind end. Throughout its course it receives, in the living state, nerve fibers to a total number of perhaps 14,000. What is a plain and undivided tunnel in the dried bone is, in life, partitioned into three parts by two membranes which stretch across it. The nerve fibers by means of which we hear originate in certain curious cell-groups associated with one of these, the *basilar membrane* (*membrana spiralis* of Fig. 37).

It is supposed that the basilar membrane is shaken in sympathy with the agitation of the perilymph and that stimulation of the endings of the cochlear branch of the auditory nerve is thus brought about. Some physiologists have been led to believe that the vibration rate of the sound waves is reproduced in the rhythm of the impulses which run from the cochlea to the brain. The more common view has been that our sensations of pitch are not due to the rhythm of the impulses but to the particular fibers which bear them at different times. That part of the basilar membrane which is nearest to the blind end of the cochlea is supposed to be more sensitive to slow vibrations, corresponding to sounds of low pitch. Proceeding thence along the basilar membrane to the other limit of the

cochlea where it joins the rest of the labyrinth, we are assumed to find each succeeding segment of the membrane adapted to respond to a higher frequency. There is some evidence from disease which is favorable to this view.

Let us trace what probably happens when three pipes of an organ sound a chord. Three vibration rates cannot strictly coëxist in the air but they are represented by a fusion just as they could be on the disc of the phonograph. The tympanic membrane moves back and forth in a fashion faithful to the details of this compound motion. It behaves as the diaphragm of the phonograph or the telephone would do. The ossicles transmit the peculiar type of movement to the fluid in the labyrinth. Pulses run through the cochlea and the basilar membrane is shaken. If the common conception is correct there are three sharply limited regions of the membrane which are thrown into energetic vibration. They correspond with the three components of the chord. The vibratory motion which was at first compounded of three elements is now resolved again into three. Three streams of impulses run simultaneously to the brain and our sensation of harmonious sound is the result.

We contrast musical sounds with noises. The physical difference lies in the fact that a musical sound has a regular rate of vibration sustained long enough to define its pitch. A noise has either too many components to give the impression of precise pitch or its pitch is too rapidly shifting. The chief difference between singing and speaking is that in the first case a succession of definite pitches can be recognized, while in the second the vibration rate is changing every instant and only a rough judgment of average pitch can be formed.

CHAPTER XI

THE EYE

All kinds of organisms are affected by light. We have seen that its influence upon the simpler forms, especially those not protected by pigment, is generally destructive. In less intensity it acts as a stimulus, modifying the behavior of the plants and animals upon which it falls. Some cells retreat from it while green plants grow toward its sources to utilize its energy in chemical syntheses. Quite low in the scale we notice animal types provided with what we call eye-spots, particles of peculiar substance which we believe to be more sensitive to the effects of light than the other protoplasm of their cells.

There is a great difference between being influenced by light and being able to see. To see we must have detailed pictures formed upon the retinas, and we must have the requisite nervous and cerebral connections to make possible the analysis and interpretation of these pictures. If ground glass were kept before the eyes we could estimate degrees of light and might notice the coming and going of large shadows. It is probable that the visual powers of many organisms, snails, for example, are no better than this. We should be subject to the same limitations if the light fell directly upon our retinas without passing through the optical systems which refract and focus it.

The human eye is a camera. It is a globe about 1 inch in diameter with a small area projecting in front as though a second globe of less diameter were imbedded in the larger one. The region which projects beyond the regular curvature of the eyeball is exquisitely clear.

It is called the *cornea*. The rest of the eyeball is white and nearly opaque. The eye is lodged in a deep recess of the skull. It has a cushion of fat behind it and six small muscles are inserted in it. The optic nerve runs back to the brain from a point which is not at the center of the eyeball but distinctly to the nasal side.

The eye is protected by the lids. When these are brought together there is a sac formed which extends over about half the eyeball. It is a mere slit when viewed with reference to its other dimension but it contains a small quantity of tears. Glands under the overhanging



FIG. 38.—The right eyeball with some of its muscles in the shelter of the orbit.

eyebrow secrete the tears into the sac behind the upper lid. The liquid spreads downward and inward over the surface of the eye to reach two little openings near the inner angle of the lids whence a duct provides for drainage into the nose. The tears serve to wash the eye and preserve it from drying effects. The response of the glands when a foreign body has struck the cornea is reasonable, but that in emotional crises is hard to account for.

The eyeball is described as composed of three coats. The outer one is tough and dense; the cornea is a part of it. The middle coat is distinguished by the rich-

ness of its blood-supply; it seems to be specially concerned with nutrition. The innermost coat, reminding one of the plate or film in the camera, is the retina. It consists in part of nerve fibers which run from every region of it to the point of departure of the optic nerve. This nerve, in leaving the eye, necessarily perforates the middle and the outer coats.

The middle coat adheres to the outer everywhere but

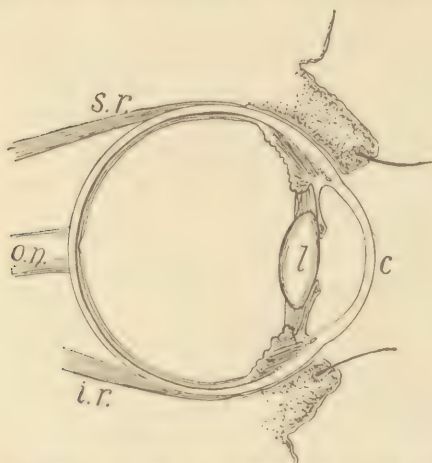


FIG. 39.—A vertical section of the right eye and its lids. (*c*) is the cornea, (*l*) the crystalline lens, its margins shielded by the iris, (*s.r.*) is the superior rectus muscle, (*i.r.*) the inferior rectus. The optic nerve (*o.n.*) is not cut by the section but is to be thought of as lying back of its plane, that is, toward the nose.

in front. Within the circle of the cornea it falls back and forms the *iris*, pierced by a round opening, the *pupil*. The iris is the part which gives the distinctive color to the eye. It is provided with muscle fibers of the smooth variety adapted to narrow or to widen the pupil. The iris serves the same purpose as a diaphragm in a camera; it limits the admission of light when the illumination is strong and it has another use which will be pointed out presently. The circular form would seem the natural

one for an opening serving such purposes and it is hard to imagine why it should be a vertical slit in the cat and horizontal in the horse.

Behind the pupil is hung the dense but elastic body which is called the *crystalline lens*. The name is somewhat unfortunate for it encourages the idea that this is the only lens in the optic system. In reality it has a smaller share in refraction than that borne by the cornea. It is of interest most of all because it is adjustable. It is convex on both surfaces but less so in front than behind. The presence of the lens separates the interior of the eye into a smaller cavity between it and the cornea and a larger one between it and the retina. Both these spaces are filled by fairly clear material, the *aqueous humor* before and the *vitreous humor* behind the lens.

The firmness of the eyeball is essential to its usefulness, for any optical instrument must have a fixed form. The eye resists deformation not so much because of the strength of the outer coat as because of the high internal pressure which prevails. This is derived indirectly from the pressure of the blood in the arteries and the result may be compared with the firmness developed in a tire when it is inflated. When the pressure of the blood falls at death the eye is soon soft and sunken.

Through the combined effect of the cornea and the crystalline lens a picture is made upon the retina. As in any camera the image is upside down. It is very foolish to make much of this fact, as people often do, for there is no reason why we should not become accustomed to the order of things we have always known and grow to regard the opposite relation as an inversion. One of the first lessons learned by a baby is to reach in a certain direction when an object makes a certain retinal impression. If the image is high on the retina he must reach down, while if it is low he must reach up. Without knowing anything at all about the retina he soon reacts unerringly.

Accommodation.—A camera must be focused with reference to the distance of the features to be brought out in the photograph. If it has been used for a landscape and is next to be used for a portrait the plate must be set farther back from the lens. The same problem exists for the eye but it is not met by changes of depth. Instead, the lens is made to assume a more pronounced curvature, so far as its front surface is concerned, when the attention is directed toward anything near at hand. This is accomplished by the contraction of smooth muscle distributed in the middle coat of the eyeball in the region surrounding the iris. We cannot discuss here the mechanics of the act. The normal eye is defined as one which forms clear images of distant objects without effort. The act of accommodation is for near vision and has a limit which is easily discovered, the shortest distance at which we can clearly see details. When the attention is shifted to something far away the adjustment is a passive one; we do not speak of accommodation in this case but of the relaxation of accommodation.

It can be observed that when accommodation for near vision is employed there is a contraction of the pupil. This is explained as follows. In any lens that can be made the central part is more satisfactory for the formation of an image than the marginal part. In microscopes, telescopes, and cameras diaphragms are used to limit the passage of rays to the central portion of the lenses. The more convex a lens is, the more essential this restriction becomes. Therefore, when the crystalline lens has been rounded for the purpose of accommodation, it is desirable to make the pupil narrower than it may be when the lens is less convex. In technical language, the small opening is said to “diminish spherical aberration.”

The extent to which the lens can be made to change its shape is greatest in childhood and is progressively lessened with the passing of the years. A man with

normal eyes who has reached the age of forty-five usually finds that he cannot focus small type. He must begin to use convex glasses for reading. It should be pointed out that when he puts on his glasses he is adding to the total refracting power of his optic system and the principle of accommodation—extra convexity—is still utilized. The supplementary lens is placed in front of the eye when the lens inside can no longer be rounded up to meet the requirement. The loss of the capacity for accommodation which comes with advancing age is called *presbyopia*.

Defects of Vision.—A person who is near-sighted has an eyeball which is deeper than normal. The result is the same that can be demonstrated with a camera: if the distance between the lens and the plate is too great for general work there will be sharp images of near objects but a blurred background. The act of accommodation makes a near-sighted eye worse than when at rest. Accordingly, the near-sighted have little use for accommodation. In old age they may be very proud of the fact that they can read without glasses.

Glasses to correct near-sight must be concave. Their effect is to postpone the meeting of the rays which are to be focused until the retina has been reached. Such glasses have a function just contrary to that of accommodation. They sacrifice near vision in favor of distant. Provided with them, the near-sighted person has normal vision for distance and uses his accommodation power for near work as the normal subject would do. Sometimes a condition resembling near-sight may exist for a time and presently correct itself. This is due to a persistent contraction of the accommodation muscle which the victim cannot inhibit.

The term far-sight is often used to indicate superior visual power. But it is better reserved to indicate an abnormality. The trouble here is that the eyeball is too shallow. When the nervous mechanism is at rest nothing is strictly in focus for the far-sighted eye. The facts can be verified by closing the bellows of a camera

until the plate is too near the lens even for the distant landscape. There is this great difference between near-sight and far-sight: that in the former accommodation makes matters worse while in the latter it establishes clear vision.

The sufferer from far-sight gains a satisfactory picture of the distance by using a moderate degree of accommo-

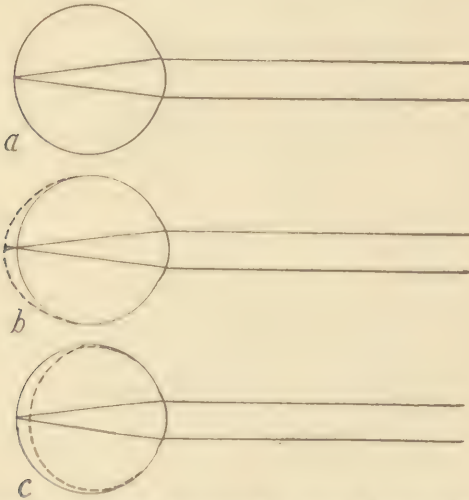


FIG. 40.—(A) suggests the normal eye, focusing parallel rays, that is, rays of distant origin.

(B) is a near-sighted eye, outline dotted; it is too deep to focus such rays but adapted to certain rays from near objects.

(C) is a far-sighted eye, outline dotted, too shallow for any focus until the accommodation power is used.

dation effort. To read he must redouble the strain. He accomplishes his purpose, but at a cost to his nervous system which is likely to be evidenced through headaches, indigestion, and other disorders. A convex glass supplies the extra refraction needed by the far-sighted and relieves him from the necessity of providing it constantly by his own effort. Comparing the near-sighted and the

far-sighted eyes, and supposing that glasses are not used, we see that the near-sighted person does close work with a minimum and the far-sighted with a maximum of strain.

Astigmatism.—This is a general term covering all defects of vision due to the departure of any of the refracting surfaces from the spheric curvature which such surfaces should have. The most common type for which glasses are prescribed has been simply and clearly described as “spoon-shaped cornea.” In the language of geometry the cornea is ellipsoidal instead of spheric. The spoon bowl which stands for the astigmatic cornea must be thought of as held with its long axis horizontal in most cases. It will then be evident that such a cornea curves more decidedly up and down than from left to right.

The optic results of astigmatism are difficult to explain in detail. The images can never be wholly satisfactory. When certain features are sharp others will be blurred. Thus in looking at a window sash one who has ordinary astigmatism will not see the upright and the cross pieces with equal distinctness. The set particularly attended to will be clearer than the others. This leads to a restless tendency to experiment with the accommodation but whenever good definition for one system of lines has been achieved the perpendicular system will have become indistinct. The strain of this uneasy process may work harm to the general health.

Glasses to correct astigmatism must have the astigmatic character themselves but in a sense opposite to that in the eyes for which they are intended. If, as usual, the excessive curvature of the cornea is up and down the lenses must curve *less* along that meridian than from left to right. The best skill is needed for the designing and mounting of such glasses. If a lens made for this purpose is turned one-quarter way (90°) round, it will double the defect which, in its proper position, it corrects.

The Retina.—It has been said that this coat of the eye is composed partly of the fibers which go to make the optic nerve. These fibers are not themselves directly sensitive to light. In fact the place where they converge to form the nerve is a so-called *blind spot*. We do not see the images of objects which are formed there. The fact that we are not troubled by this deficiency is to be explained chiefly by the circumstance that we are so much occupied with the central part of the retinal

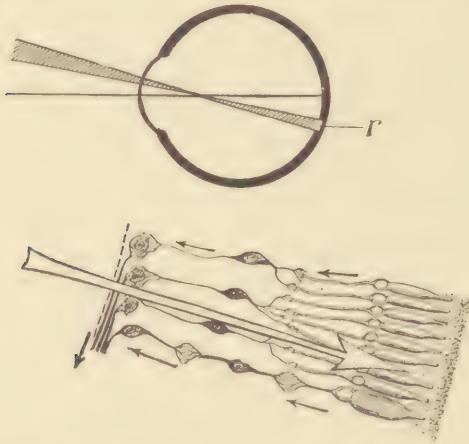


FIG. 41.—The upper diagram suggests the path of a pencil of light which illuminates a spot on the retina (*r*). It is not the optic center. Below, certain features of the region (*r*) are indicated upon a much larger scale. The white arrow, having the same direction as the rays in the first figure, shows how the light pierces to the deep or rod and cone layer of the retina. The small black arrows show how the resulting nerve-impulses are returned by transmitting elements to the inner surface of the retina where they run tangentially toward the optic nerve.

picture that we have little appreciation of the outlying part. It will be recalled that the optic nerve does not leave the center of the retina but makes its exit from a point some distance toward the nose. The central spot, before mentioned as having the best visual capacity, is called the *fovea*.

The student, when he reads a description of the several layers of the retina, has the strongest feeling that it is all "wrong side out." The cellular elements on which the light undoubtedly acts are not arrayed upon the inner surface but are on the outside, next to the middle coat. To reach them the light must pass through a tangle of nerve fibers and cells other than the true receptors. It must even pass a network of blood-vessels. The layer which finally translates the radiant energy into nerve-impulses is that of the *rods* and *cones*. At the fovea the overlying matter is reduced and the exposure of the sensitive units is correspondingly direct.

The rods and cones constitute a mosaic pavement in which the individual members are placed with striking regularity. The cones are rather more advanced and elaborate in appearance than the rods and there is little doubt that they have superior properties. In the fovea there is a central group of cones with no rods, farther out the cones are scattered among rods which greatly outnumber them, and still farther from the fovea no cones but only rods are to be found. This distribution is associated with contrasted powers of vision in these three regions.

The fovea and a zone extending some distance outside it have the capacity to differentiate all the colors. Beyond the area with complete color vision there is a tract not stimulated characteristically by reds and greens though distinguishing yellows and blues. Still beyond, all color comparison is lost and only light and shade can be recognized. We say that the outlying region of the retina is totally color-blind. The same part is without cones, so it has been natural to infer that the cones are adapted to discriminate color while the rods are affected in the same way by all varieties of light. If this is so their reactions can indicate nothing more than the degree of illumination.

Color-blindness.—What is ordinarily meant by this expression is not a complete inability to compare colors

but a confusion of reds and greens. It will be noted that in any retina there is a zone in which this confusion exists. A person is said to be color-blind when the same difficulty extends even to the fovea. Since red and green are colors used for railroad signals and for the port and starboard lights of vessels it has been found necessary to subject employes to careful tests. In the trials the candidates are not asked to name any colors, as that would be testing their education rather than their natural endowment, but they are asked to place in piles numerous skeins of yarn, putting those together which have a general similarity.

It is reported that this defect is to be found in one man out of about thirty. It is rare in women. Color-blindness is hereditary in families but, according to an odd principle, a man who is color-blind will not have color-blind sons or daughters. His son's sons will also be free from the defect and all his granddaughters, but it may be looked for in the sons of his daughters. Many quaint stories are told of the mistakes made by color-blind persons. A Dartmouth student with this handicap came to Boston to attend the football game with Harvard. At the last moment his friends suggested that he provide himself with a suitable green necktie and he hastened to choose one. When he displayed it there was a strenuous protest; it was the Harvard crimson.

The process in the rods and cones must be a photographic one. Some chemicals are present there which are changed in a definite way by the action of light. The changes which occur must furnish the immediate source of the stimuli which start the nerve-impulses on their way to the brain. One difference between the retina and a common photographic plate lies in the fact that in the eye the taking of each picture is followed by a marvellously rapid recovery of a condition which permits a new set of images to be registered. In the plate the outlines photographed are permanent even though they may be overlaid by those of a second

exposure. We may say that in the one case there is great resistance to fatigue while in the other it is almost immediate. The retina, however, does show a measure of fatigue under strong stimulation.

A retinal picture, when the eyeball is stationary, must consist of a vast number of associated points. In this respect it resembles a half-tone reproduction. In either instance the points are so numerous and so close together that no discontinuous effect is noticed. When we try, in imagination, to correlate these points of excitation in the retina with simultaneous streams of nerve-impulses in thousands of fibers of the optic nerve and with the multitudinous brain-processes which result from their arrival at the centers we realize the hopeless difficulty of the analysis. The situation becomes still more amazing when we consider that we can move the eye, shifting each detail of the picture from certain retinal cells to others, and yet have the same general impression as before. By our movements we cause chosen features of the scene to pass in succession over the fovea while the sense of the larger relationships of all the things we see remains steady and reliable.

Binocular Vision.—How are we served by having two eyes instead of one? In answering this question it is necessary to point out that we do not profit from our double equipment in the same way that some animals do. The chief value of binocular vision in a fish is that stimuli can be received from nearly opposite directions at the same time. Roughly speaking, if one eye is looking east the other is looking west. We gain only slightly in the width of our visual field through having two eyes. Our principal gain is in what is called stereoscopic vision.

Stereoscopic views are photographs taken in pairs from points somewhat separated. Such views are not duplicates. Their more distant features are nearly identical but the details of the foreground are differently placed in the two and the more differently as they are nearer

the camera. In the same way, the picture on the retina of the right eye is unlike that in the left eye and most markedly as regards things which are close at hand. We have learned by experience—without thinking about it in any analytic way—that dissimilarity of retinal pictures is associated with nearness of objects. So binocular vision becomes a great aid in forming judgments of distance.

As this is true for distinct objects so it is for various parts of the same object. Looking at a building with both eyes we have a vivid impression of the projection or recession of its angles. We say that we gain in this way the sense of solidity. Stereo-binocular glasses are made with the object lenses farther apart than the lenses which are held to the eyes. As a result the user has not only a magnified picture to look at but enjoys the advantage that would be his if his eyes could be moved apart and made to converge upon the scene. The principle is that of the surveyor's triangulation and also of the range finder.

Judgments.—In speaking of binocular vision we have given an idea of one way in which we estimate the comparative distances of things seen. There are other ways in which this is done. Even with one eye we have a fair basis for drawing conclusions. It may be laid down as a general principle that motor acts are attended with characteristic sensations. This is true of the act of accommodation. When the attention is directed to a surface like the page of a book which is only a few inches away there is a strong tension on the part of the muscle that increases the curvature of the lens. A feeling goes with the maintenance of this tension and this feeling has, from early life, been associated with looking at that which is near at hand. One source of the bewilderment experienced on first wearing glasses is that the accommodation effort for a given distance is greater or less than before. New interpretations become necessary.

When both eyes are used there is another muscular effort besides that of accommodation. This is the strain of *convergence*, increasing as the attention is directed to things close by and diminishing as we look off to the distance. It will be evident that the two eyeballs must be rotated considerably inward to bring the images of the same word on the printed page to both the foveæ at once. Failure to bring the same images upon the foveæ results in double vision.

So far we have mentioned the stereoscopic principle, accommodation strain, and the sense of convergence as contributing to our judgments of distance. Other matters enter in. There is perspective, the fact made familiar from experience that parallel lines retreating from the eye seem to approach one another. There are effects of overlapping in the landscape, more distant features projecting from behind those that are not so far away. There are atmospheric qualities, hazy or bluish appearances which we assume to denote distance. Then, too, when we know the size of an object and have an unusually small image of it formed upon the retina we infer that it is remote. So the apparent size of the human figure often helps us to estimate its distance from us and so the distance of associated objects. These devices can be used in painting upon a flat surface and produce the desired effects in the absence of stereoscopic properties and differential accommodation.

Generally speaking, we must judge distance before we can judge size. It has just been said that the magnitude of the image of a *familiar* object helps us to say how far away it is but its size must be certainly known if this is to be true. Bodies like rocks, which may be of any size within the widest limits, cannot be judged as to their actual bulk until their distance is established. The discussions which people indulge in regarding the size of the moon show how futile are our attempts to conceive of size when there is no adequate sense of the remoteness of the object under observation.

CHAPTER XII

THE HYGIENE OF THE NERVOUS SYSTEM

In previous chapters we have given some account of the nervous system and the sense-organs. We have seen that, from an objective point of view, the purpose of the nervous system is to transmit impulses derived from external stimuli and to apply them through the effectors (muscles and glands) to secure useful adaptive reactions. The health or normality of a system with such a duty is clearly all-important. In this chapter we shall treat of its conservation in the briefest fashion.

Habit.—It is a property of the brain to be modified by use. We say that paths of easy transmission are formed in it when certain acts have been repeatedly performed. This is the basis of skill and economy of power. It is nearly related to the formation of habits. A habit may be considered an acquired, personal reflex, as we have already suggested. Things which are habitual we speak of as “second nature” and if we stop to consider what this means we shall find the idea to be that certain circumstances lead regularly to certain performances.

The capacity to form habits is of the greatest value. As we master one accomplishment after another we are set free from irksome attention to details and can attempt something new. A child that is putting on its clothes may not be able to think of anything but the task at hand; the same is true of the youth who first applies the razor. Thanks to the emancipating virtue of habit-formation, the grown man dresses and shaves while his mind is busy with more interesting matters.

No one would wish to change those habits which obviously help to support all the useful activities of life.

There are, on the other hand, all manner of habits which are bad in the sense that they detract from one's efficiency, injure health, or are unbecoming. These are to be broken up when recognized with all possible energy and decision. Their exhibition by other people is to be viewed with a wholesome resolution not to fall into such ways, though the pharisaic spirit is to be avoided.

One of our wisest teachers, the late William James, pointed out that there are many habits which are not particularly good nor distinctly bad; they are accepted by our associates without praise or blame. It was the teaching of James that such indifferent habits afford us a most valuable sphere for mental training and self-discipline. We can use our will power to change them in radical ways, substituting one practice for another by deliberate choice. Such exercise is attended with a highly pleasurable sense of being master of oneself and one's situation. It is easy to find scope for the effort in the realm of our speech: to abandon a favorite phrase in favor of another, to cast one's sentences in a new mould.

This voluntary regulation of minor habits gives a kind of control which may be a real asset in meeting crucial temptations. It is also a means of postponing old age. It has been said that the aged nervous system is one which records the past, holding little promise of future modification. Its "ruts" are deep and fixed. To change these ruts often in early and middle life probably delays the coming of senile rigidity. It is to some extent in our power to preserve the plasticity of the cerebral organization and it is worth the cost.

Inhibition.—The self-command that has been recommended is largely a practice of inhibition. We have said before that this is an eminent human capacity.

It is shown in refraining from motor acts and quite as truly in mental life. We need two great accomplishments for intellectual success, the power of *concentration* and the power of *detachment*. These seem to be opposites but they are really akin. To concentrate is to banish thoughts which are irrelevant to our problem and to detach is to put aside the problem itself when this is desirable. Great men and women have excelled in both respects; they have been able to narrow their attention to the work before them and, again, to enjoy absolute relaxation or to sleep when they have thought it opportune.

Anticipation.—It is often necessary to muster all our resolution to exclude thoughts of the future. At other times it is the part of wisdom to live much in anticipation. Under normal conditions one should find interest and happiness chiefly in the activities of the present. Much is written nowadays of the injurious effect of fear upon the mental and physical health and the teaching is probably not carried too far. We often see splendid examples of detachment on the part of those who approach great trials, perhaps surgical operations, without dwelling on the ordeals in prospect, taking an unselfish interest all the while in the ordinary concerns of the home. This is heroic and at the same time it is the best possible course for the individual.

In temporary misfortune anticipation of a better day may be beneficent. At the same time it is sometimes foolish to think too much of the future when the result is to create discontent with present conditions. Many a homesick student makes himself more miserable than is necessary by counting the days to his vacation and indulging in incessant plans for his holidays. He ought to find compensations in his work and his companionships.

Emotion.—The strong feelings which, as we say, at times "possess us" are attended by an outpouring of impulses from the nervous system to various effectors.

How extensive and potent is this discharge has only recently come to be appreciated. When a man shows anger we can recognize by the tension of his muscles that they are under stimulation. If he is pale we may conclude that his circulatory system is involved in the reaction. His fast heart would confirm this opinion. We may state here what will be more fully described at another time; that the alimentary canal and the glands are also played upon by the impulses that issue in moments of excitement.

In the light of the facts emotion is seen to be a very real form of exercise. As exercise may be wholesome or unwholesome, reasonable or excessive, so emotion may count for health or dispose to disease. Every intelligent man has constantly brought to his attention conditions and movements which his judgment condemns. He cannot afford, however, to indulge in heated indignation toward all these things. Righteous anger is profitable only when active work for a cause is to be undertaken. To feel intensely and not to act is as ill-advised as to run the engine of an automobile for long periods while the car is standing still. People who do not have many emotional stirrings are, in a sense, untrained and may be wanting in endurance. On the other hand, intense and frequent emotion is a source of nervous fatigue. This must now engage our attention for a little.

Nervous Fatigue.—We have said something about the fatigue of the neuromuscular mechanism. It will be recalled that the motor end-plates and the muscle fibers themselves are subject to temporary loss of capacity through use. The nerve cells may also be vulnerable; the white matter is highly resistant. The synapses through which effects are transmitted from one unit to another are quite susceptible to fatigue. When we have to do with the intricate organization of the brain we cannot so easily analyze what we call a state of fatigue. Fatigue that is severe and sharply localized probably means in every case a loss of power

to act, but diffuse fatigue in the central nervous system has another characteristic; it resembles an intoxication in which there is much unprofitable activity.

Perhaps we may recognize two types of nervous fatigue. There is the daily weariness which leads to sleep and is neutralized in the course of the night's rest. The other sort is more insidious and has the perverse symptoms of seeming stimulation. It is a state of hypersensitiveness and unrest. The victim is unable to relax and aggravates his abnormal condition because of the fact. An advanced case of nervous fatigue may deserve the name of *neurasthenia*.

The neurasthenic is too easily affected by stimuli. He feels every discomfort more keenly than he should. He is distressed by the weather, his clothes, his chair, and his bed. Noises irritate him; so does bright light, and so do certain odors. His nervous system is thus shot through with many more impulses than should properly penetrate it and the responses are in proportion. There are the motor signs which we think of as manifestations of nervousness: the continual shifting of position, useless movements of hands and feet, tricks like twirling the moustache or toying with the eyeglasses.

When we have tangible evidence that the nervous system is showering impulses upon the skeletal muscles it is not hard to believe that it is acting upon other effectors in a similar way. But the fact is to be borne in mind that many of the currents which run out to the viscera and the blood-vessels are inhibitory. So, while a nervously tired person is pretty sure to present a picture of restlessness, some of his organs may be hindered rather than spurred on in their working. This is particularly the case with the alimentary canal.

The details of the nervous regulation of the digestive tract can best be taken up at a later time. But from what has been said it will be plain that excessive activity at the centers will be likely to interfere seriously with the execution of its functions. Nervous indigestion is to

be expected. This springs in part from the suppression of the secretion of the gastric juice and in part from the retarding of the motor mechanisms of the stomach and intestine. The progress of food is delayed and so is its digestion. As a result there is constipation, abnormal decomposition of the intestinal contents, and gas formation. More or less poisonous products of putrefaction may be absorbed into the circulation and do mischief, a prominent consequence of such absorption being an increased demoralization of the nervous system.

Other functions which suffer are the action of the heart and the control of the blood-vessels. The last-mentioned disturbance shows itself in great sensitiveness to temperature changes, the skin flushing or paling in response to comparatively slight shifts. The perspiration breaks out at times in excessive volume and again is suddenly checked. Irregularity and instability of reaction are to be observed in every field. The kidneys, the bladder, and the reproductive organs misbehave and often encourage the sufferer in the conviction that he has grave local disease.

Meanwhile the temperamental signs are most characteristic. There is morbid absorption in self with utter disregard of the feelings and rights of others. Self-pity is a leading symptom. The feelings of the neurasthenic are always being wounded but he has no realization of the injustice he inflicts upon his housemates. He is unreasonable and exasperating. It is one of the most difficult of life's duties to deal kindly, firmly, and consistently with such people. They deserve sympathy but the free expression of it confirms them in their pessimism. The problem is too large a one to be discussed in a book like this.

Naturally the cure for nervous fatigue must be found in rest, but the high irritability which prevails makes it difficult to secure the rest which is so obviously needed. Some strong inhibition must fall upon the overdriven

complexes of the nervous system before they are restored. In different cases this requisite inhibition is secured in very different ways. Sometimes hard and simple manual work will induce it. Sometimes a deliberate withholding of sympathy from a nervous subject, a steadfast refusal to give him the center of the stage, has worked wonders. He has silenced his own complaints and mastered his own situation. In many cases a religious or semi-religious ideal, a conviction of a great and restful reality beyond oneself, has steadied the feverish system and given it poise.

Of course the progress of recovery is helped by many conditions that may be controlled. The causes that led to the trouble are to be removed so far as they have been discovered. They may be physical disorders, calling for medical, surgical, or dietetic treatment. The wearing of proper glasses may be important. So far as the disturbing factors have been in the nature of care, worry, domestic friction, and disappointment, the circumstances must be made easier where this is possible and fresh interests are to be invited. Life needs to be simplified until it does not seem distracting but it must not be made stagnant. Outdoor exercise is essential.

Rest and Sleep.—We have seen that extreme fatigue fails to bring automatically the rest which is desirable. But ordinarily in health the inclination to rest after activity is fairly trustworthy. The question is often asked how far a change is a rest and how far actual repose is to be insisted on. It is probable that some strenuous individuals have pushed the doctrine that a change is a rest farther than it should be carried. It is a truth with limitations.

The most complete rest is in sleep. In this state we spend about one-third of our lives. Its nature is not wholly clear but it may be said that to be awake is more wonderful than to be asleep. The evident fact is that the sleeping brain, particularly the cerebrum,

is in a condition of reduced activity. Decerebrate animals still appear to alternate sleep and waking, thus showing that the change from one to the other occurs in some degree in the brain-stem. From our human standpoint we think of sleep as a suspension of consciousness or at least a shutting out of impulses from the receptors and a great diminution in those going to the muscles. The going and coming cannot entirely cease; breathing goes on and many of the simpler reflexes can be elicited.

Aside from natural sleep there are two circumstances which commonly suspend consciousness. One is the temporary poisoning of the brain by drugs and the other the type seen in fainting when the cerebral circulation has partially failed. Is our sleep more like anesthesia or like fainting? It is likely that it has points of resemblance to both. It is like anesthesia in that fatigue substances gathering in and about the brain cells probably dispose to it, but it is like fainting also inasmuch as the final relapsing from waking to sleep is believed to depend on the lessening of blood flow through the brain. A person can ordinarily be waked quickly from sleep but not from anesthesia. The stimuli used to overcome faintness would also serve to rouse a sleeper.

The simplest way to picture sleep is perhaps to assume that the central fact is a high resistance affecting many paths. A blockade anywhere between the sense-organs and the cerebral cortex would account for the failure of sensation. A similar block on the path from the motor areas to the muscles would result in relaxation and quiescence. The interruption of association channels would interfere with the synthetic processes of thought. The dreaming consciousness, when we realize it at all, has a character which suggests that the sensory currents are much impeded and we know that the motor expression is generally limited.

The first hour of the night's sleep is one of rapidly deepening stupefaction. This has been proved by

measuring the intensity of stimuli, such as sounds or electric shocks required to wake the sleeper. After the first hour a shoaling of sleep soon begins and goes on at such a rate that one would predict waking within two or three hours. Instead of this there is a long period of light sleep from which one is easily roused. This is not the same as saying that one is easily kept awake, for the shallow sleep toward morning is readily resumed after an interruption. The nervous shock experienced when one is awakened from the deep sleep of midnight is vastly more severe than the excitement created by the alarm clock at 6 a.m.

Certain writers on hygiene, having in mind the maximum efficiency of the man, urge that sleep be reduced to six or to five hours a day. It is hard to decide whether such teaching is universally to be applied. There would seem to be a real danger of overtaxing the nervous system. Yet it is probably true that many people waste time in sleep. This is most apt to be the case with heavy eaters who are commonly heavy sleepers as well. Overeating seems to produce changes in the composition and distribution of the blood that favor drowsiness. Consistently with this light eaters are often sufferers from insomnia.

When we wake from sleep we may or may not recall that we have been dreaming. If we have recollections of the mental currents that have run their course while we slept we can usually say whether we have been much concerned with the cares and interests of our present life or whether we have been watching curious pictures founded on scenes long past and, as we supposed, forgotten. The best sleep is probably that which seems to have been dreamless as we look back upon it but if there are dreams it is not desirable that they should be of actual, present affairs. It is a sign of nerve-fag when the thoughts of the night closely resemble those of the day. When a healthy man goes to sleep he may have very much the same experience as though he entered a moving

picture show. He may witness a rapid succession of strange and exciting scenes the order and personnel of which he could by no means have anticipated. They pass from his recollection, for the most part, as quickly as the views on the screen. Perhaps they constitute a legitimate recreation.

Alcohol.—While we are dealing with the hygiene of the nervous system some attention may be given to this much debated subject. Alcohol has other relations to human life than the influence which it exerts upon the brain but this is by far its most important aspect. It is a potential food, a relish, and sometimes a drug, but it is not much sought for these properties. It is prized chiefly as a comforter, that is to say, for its temperamental effects. These effects are apt to be described as stimulation but it is doubtful whether the word is wisely used.

A group of men who have had some wine at dinner are observed to become talkative and animated. They gesticulate and laugh more than they would ordinarily. They may become decidedly uproarious. Is this not stimulation? It has been generally held to be, but another interpretation can be offered. The suggestion has been made that what we are witnessing is a *withdrawal of inhibition*, the paralysis of the highest centers with a consequent release of the lower from their regulation. If a train is descending a grade there are two ways to account for an increase of speed: more power may have been applied by the engine or the brakes may have been taken off. The action of alcohol has been defined by most writers as a taking off of the cerebral "brakes."

It may be an open question whether this removal of inhibition is always an evil. Able thinkers have justified the artifice. Men have resorted to it for ages to secure social ease and to banish cares. But it does seem as though abandoning oneself to convivial pleasures should be a simple act of the will rather than a reaction secured

by a dose of narcotic. We have urged that the power of detachment is an accomplishment to be desired and cultivated; one should not be obliged to depend on alcohol for its realization. The wine opens a royal road to a goal which it is often well to seek, but it is a downhill road and the return cannot be so easily effected as the descent. The man who is really master of himself can detach and concentrate with equal success; the alcohol favors the former but in the same measure is opposed to the latter.

The tendency to form a habit in the use of alcohol is not to be made light of. Two young men whose heredity and principles seem to be equally good may differ absolutely as to the degree of safety with which they can drink. One may enjoy it from time to time and feel no desire to increase the frequency or the extent of his indulgence. The other may prove to be one of those unfortunates who cannot remain temperate—one who will go on to his own ruin and to break the hearts of his family. Total abstinence is a safe course and it has constantly a larger number of distinguished exemplars.

Tea, Coffee, and Chocolate.—These widely used preparations are mild stimulants in the best sense of the term. They increase working capacity and at the same time may give a sense of well-being. It is impossible to prove that their use is harmful for the great majority of people. Many individuals have found that these beverages disagree with them and such people are usually sensible enough to abstain. Some persons seem unable to make the sacrifice where it is desirable and suffer decidedly in consequence. It is a good plan not to resort to these stimulants when there is no clear occasion for their use. If they are not employed regularly they will be doubly serviceable in a genuine emergency.

CHAPTER XIII

THE ALIMENTARY CANAL. DIGESTION

In Chapter II some general statements were made in regard to the origin and service of food. The term was used to include things which may enter into the body as constructive material or as fuels. By far the largest share of our food, especially after the completion of growth, is valuable purely as fuel. We have now to trace the preparation of food for absorption, its distribution and storage, and the final utilization of it by the tissues. First of all some attention must be given to the anatomy of the human alimentary tract.

The Alimentary Canal.—In all the higher animals this is a passage leading from a mouth to a vent or anus. The contents of the canal are not to be considered as within the body but only in contact with a part of its surface. The canal in man is 25 or 30 feet long, the great length being made possible by the coiling of the intestine in the abdominal cavity. A long canal is not any more capacious than one shorter and wider, but it has more surface and this is important since through the lining of the tract the useful part of the food is received into the blood.

The successive parts of the canal are the *mouth*, the *pharynx*, the *esophagus*, the *stomach*, the *small intestine*, and the *large intestine* or *colon*. The large intestine terminates in the *rectum* leading to the anal outlet. The arrangement of the structures about the mouth is sufficiently familiar. The pharynx is what we often call the throat, a short section common to the digestive and the respiratory systems. In it the course taken by the

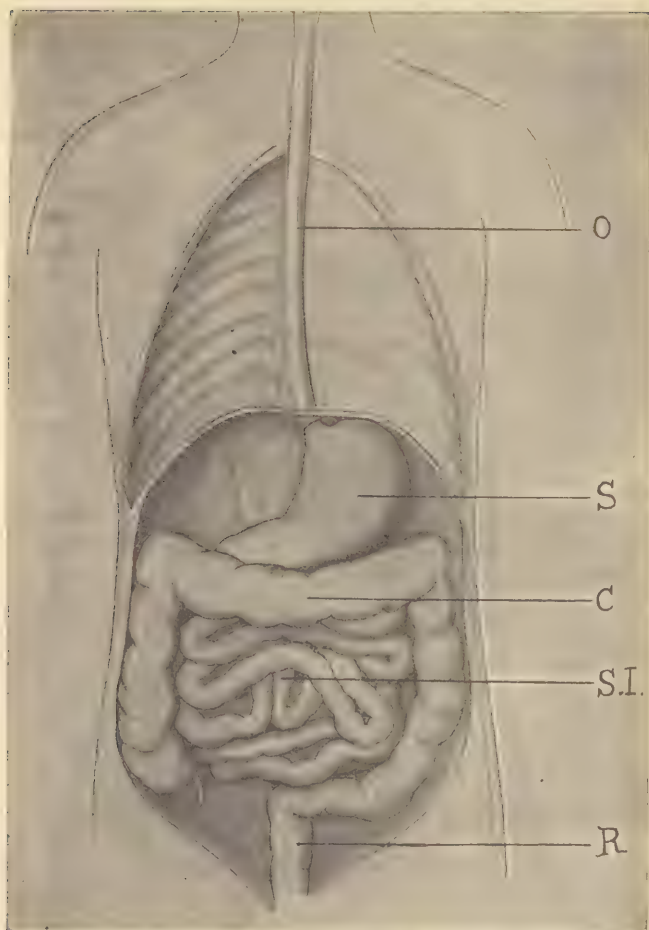


FIG. 42.—The human alimentary canal shown diagrammatically: *O* is the esophagus; *S* is the stomach; *S.I.* suggests the small intestine; *C* is the colon; *R* is the rectum. The connection between the stomach and the small intestine occurs behind the transverse colon, which also hides the pancreas.



FIG. 43.—Relations of the mouth and nose. This is a vertical section through one nostril, and therefore slightly away from the mid-plane of the head. The convoluted character of the lateral wall of the nasal cavity is suggested. The connection between the nose and the throat will be seen behind the soft palate (*P*); *L* is placed in the larynx, above which is shown the spur of the epiglottis; *O* indicates the course of the esophagus. It will be noted that the course taken by the food crosses the route of the breathing in the pharynx.

air we breathe crosses that of the food we swallow. The *larynx*, which is ventral to the lower part of the pharynx and under the tongue, belongs to the respiratory tract exclusively. The breath comes and goes through the larynx and the food enters the *esophagus*.

This is a tube leading to the stomach. It runs down behind the trachea or windpipe until the fork in that passage is reached; then the esophagus continues behind the heart and pierces the diaphragm. Immediately below this partition it expands into the stomach. This is a sac lying mainly to the left of the middle line and higher up than is popularly supposed. It is within the ribs as viewed from the side and could be reached from in front by an incision just below the end of the breast bone. The *spleen* is in the limited space to the left of the stomach while the much larger space between it and the right ribs is filled by the great mass of the *liver*.

The shape of the stomach varies according to circumstances but it may be said to have somewhat the form of a pear, the small end being directed downward and to the right. The small intestine takes its departure from this tapering extremity. A line drawn from the place where the esophagus enters along the upper border to the place where the intestine leaves is said to follow the lesser curvature. The much longer line connecting the same points but following the lower border defines the greater curvature. The opening from the esophagus to the cavity of the stomach is the *cardia*; that from the stomach to the intestine is the *pylorus*.

The small intestine is the longest division of the canal, having a course of about 20 feet. It is coiled in a manner which defies description and it ends by joining the colon near the right hip bone. Its first turn after leaving the stomach is called the *duodenum* and it encircles the head of the *pancreas*. Beyond the duodenum the small intestine is rather vaguely divided into two sections, the *jejunum* and the *ileum*. The words

large and small applied to the intestine have reference to the diameter, not the length.

The colon ascends on the right side of the body until it is overhung by the liver, then crosses to the left just below the stomach, and finally comes down on the left side for a certain distance. Turning toward the back it curves around to the mid-line, forming a segment known as the *sigmoid flexure*. From this the rectum

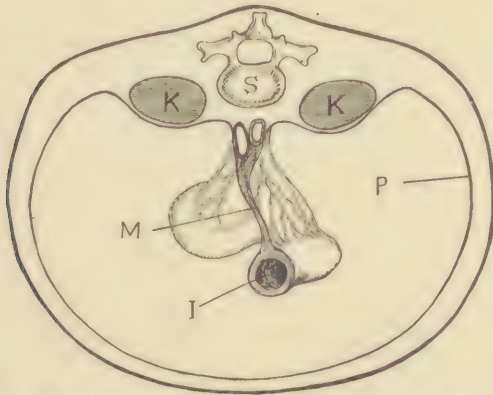


FIG. 44.—This is an entirely schematic section across the human body in the mid-abdominal region: *S* indicates the spine; *K*, the kidneys; *P* is the peritoneum, the lining of the abdominal wall. It is prolonged from the back to form the mesentery (*M*), which extends to and around the loop of intestine (*I*). The large unoccupied space shown does not really exist, for successive portions of the alimentary canal together with other organs completely fill the cavity.

descends in front of the lower bones of the spine and reaches the anus. A rough diagram of the colon resembles a question mark.

When the abdominal cavity is opened the first impression is that the intestine lies loosely within like a coil of rope. But if a loop is chosen at random and lifted from its place a clear, glistening sheet of tissue is found attached to it. This is the *mesentery* and it can be followed to an attachment to the dorsal body wall.

Thin as it is it must be thought of as a double sheet between the two surfaces of which run the blood-vessels, nerves, and lymph-channels of the intestine. The tube of the intestine itself should be conceived of as wrapped round by the mesentery. One writer has compared it to the clothesline over which a blanket is hung. Thus the continuation of the mesentery makes the outer or *serous coat* of the canal.

At its other border, where the mesentery reaches the dorsal boundary of abdominal cavity its two layers part and spread to be continued as the lining of that cavity, the *parietal peritoneum*. The shape of the mesentery when entire is difficult to visualize; it must be thought of as following the whole length of the small intestine and much of the large and yet contracted to join the wall of the body along a rather short line of insertion. The resulting structure has been compared with a "ruffle" or "flounce." The stomach has a suspending membrane which is really a mesentery but referred to as the lesser omentum. It comes to the lesser curvature of the stomach from the under side of the liver and is continued over the surface of that large organ to its attachments to the diaphragm and the back of the cavity.

The serous coat of the stomach leaves the greater curvature of the organ as well as the lesser and the double sheet so formed hangs slack in front of the intestine like a short apron, the *great omentum*. This is folded at its lower limit and returns to the transverse part of the colon. The great omentum sometimes comes to be a ponderous appendage from the accumulation in it of adipose tissue.

The Digestive Glands.—Associated with the alimentary canal are the organs which deliver into its interior the juices required to prepare the food for absorption. These are called glands but the reference is sometimes to bulky organs like the liver and sometimes to microscopic features of the lining of the tract.

When we take up the minute organization of these parts we shall see that the usage is reasonable. Glands which are placed distinctly away from the canal have *ducts* leading to it for the discharge of their secretions.

Three pairs of *salivary glands* contribute saliva to the mouth. On either side there is a *parotid gland* below and before the ear. Its duct runs forward to empty on the inside of the cheek opposite the upper molar teeth. The *submaxillary gland* is near the angle of the jaw; it has a duct opening under the tongue close to its fellow from the other side. At or near the same point comes in the secretion of the small *sublingual gland* which is under the floor of the mouth.

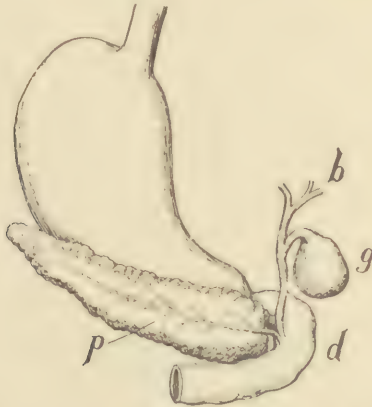


FIG. 45.—A diagrammatic sketch of the stomach from behind. This unusual point of view serves to show how the bile-duct, originating from branches in the liver (*b*) and connected with the gall-bladder (*g*), unites with the main duct of the pancreas as the two enter the duodenum (*d*); (*p*) is the pancreas with the course of the duct along the axis of the organ dotted.

Glands of a microscopic order discharge by openings that may be spoken of as pores over the entire lining of the stomach and intestine. They secrete the *gastric juice* into the stomach and the *intestinal juice* or *succus*

entericus into the intestine. Their occurrence in the lower divisions of the canal is less abundant than higher up. The pancreas has a chief duct uniting with the small intestine just below the pylorus. At the same place the *bile duct*, bringing the secretion of the liver, reaches an outlet. The two ducts practically come together in the act of entering the intestine. The spleen has no duct and is not strictly a gland.

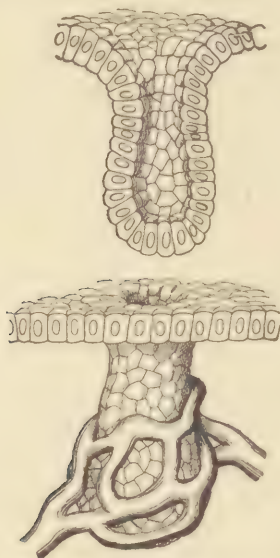


FIG. 46.—The principle of glandular structure. In the upper figure a simple microscopic gland is supposed to be laid open by a section along its vertical axis. The cells are seen to surround a recess into which they discharge their secretion. Below, the same structure is shown in its entirety, and in addition the encircling blood-vessels which contribute to make good the losses suffered by the secreting cells.

The Minute Structure of the Organs of Digestion.—The outer coat of the stomach and intestine has already been mentioned, a continuation of the mesentery and so of the peritoneum. This covers the muscular component of the canal which is resolved, so far as the small

intestine is concerned, into an outer layer in which the fibers have a longitudinal direction and an inner and thicker one in which they are transverse or circular. The cells in these layers are of the smooth type (Chapter IV).

Inside the muscular coats there is more or less loosely woven tissue rich in blood-vessels and nerves. Still within this and next to the hollow of the canal is the epithelium or *mucous membrane* which calls for a careful description. It is a single layer of cells which are individually prismatic in form with their long dimension vertical to the free surface. All that enters the body from the alimentary system must pass through or between these cells. The term mucous is used because this epithelium is overlaid with a slimy film more or less protective in function, the product of certain specialized cells.

The lining epithelium is not to be thought of as a smooth expanse; it is raised into many prominences and depressed into many pockets. The pockets of the epithelium are the minute glands to which reference has already been made. We must now take pains to make clear the relations of such glands. Many variations in their shape are to be found but we may assume that a fair type is furnished by a slender cylindric pit. Such a pit may be likened to a well, the cells in its walls being quite suggestive of regularly ordered masonry. But it must be pointed out that the cells close in the bottom of the gland where no stones would usually be laid in a well.

The secretion from a gland is produced by the cells which bound the cavity. These cannot go on discharging water and dissolved substances unless their losses are made good. They must receive supplies from the lymph which lies at their submerged extremities. The lymph itself is a limited source and must be renewed by the blood which is led through a network of fine vessels in close proximity to the secreting cells. A gland ap-

pears like a filter, adapted to remove something from the blood while keeping other constituents back. Secretion, however, is much more than filtration. The material derived from the blood is often greatly changed during its stay in the gland cells and so we find many bodies in the product which are not to be found in the blood.

It is necessary now to show that the custom of applying the word gland both to minute developments of the alimentary mucous membrane and to massive organs like the liver can be justified. The fact is that an organ like the liver or the pancreas is a vast aggregate of secreting recesses which individually are much like the simple glands of the stomach and intestine. The branching ducts provide for the gathering of the combined secretions from all these units. A large gland may be expected to have a supporting capsule and partitions of connective tissue subdividing it into lobes and lobules. It is to be borne in mind that many glands are as distinctly under nervous control as are the contractile tissues.

Classification of Foods.—In Chapter II the contrast between proteins and non-protein organic foods is briefly indicated. The former contain carbon, oxygen, nitrogen, hydrogen, and sulphur, sometimes phosphorus. The latter are non-nitrogenous. They may be grouped as below:

Carbohydrates, including starches and sugars.

Fats (or oils).

Alcohol.

Starches are incompletely soluble, of large molecule, and tasteless. They are easily converted to sugars which are freely soluble, of small molecule, and sweet. Fats have familiar physical characters: low melting-points and insolubility in water. They contain the same elements as carbohydrates: carbon, hydrogen, and oxygen (much more of the first, much less of the last). Water and mineral salts are reckoned as inorganic foods.

The Nature of the Digestive Changes.—Digestion is often said to be a preparation of food for absorption and this is correct if it is understood in the broadest sense. A narrow conception is to be avoided. First of all, we must not think of digestion as mere solution. Before the rise of organic chemistry it was scarcely possible to have any other idea concerning it and observers judged its progress simply by the dissolving of food samples. It is true that solid food must be dissolved but there are other aspects of the process to be taken into account. Foods which are in solution may yet require to undergo digestion.

Digestion is a process of refining. It effects a separation between the valuable and the useless. But, again, this is only one feature of the change. When a food already soluble is digested it is said to gain in diffusibility. By this we mean that the power to pass through ordinary membranes, like parchment, is increased. This may be supposed to make absorption easier but, once more, the gain in diffusibility is but one of several phases in the transformation which we call digestion. With the advance of chemistry it was found that the digestive changes are always *cleavages*, large and complex molecules giving rise to new ones smaller and more numerous. This reduction in the size of molecules naturally favors diffusion.

Most significant of all, digestion obliterates many of the characters which differentiate foods and gives us at last much the same set of products whatever the meal may have been. Day by day we make different choices but we do not greatly alter the nature of the contribution made by the intestine to the blood. A comparatively small number of individual substances result from the serial cleavages which have occurred. So we may say that digestion *standardizes* our food; it prepares for the body a few acceptable compounds from the many strange and foreign ones which were taken into the stomach.

The importance of this standardization can be made clear by an illustration. Take cane sugar as an example. Here is a food which contains no waste matter and needs no further refining. It is soluble and diffusible. Yet it is not fit to be introduced into the circulation and if the experiment is tried it will be excreted through the kidneys, in other words, treated as useless material. The trouble is that it is not a *native* compound. A single change quickly accomplished in the intestine transforms it into two other kinds of sugar which the body can utilize.

Digestive Secretions.—The process of digestion is carried on under the influence of the several digestive juices. When one of these is found to have power to advance the digestion of a certain kind of food we naturally assume that an agent exists to bring about the observed effect and we call the supposed agent an *enzyme*. Enzymes are not known in an isolated or pure condition; their existence is inferred from the behavior of mixtures of a very heterogeneous sort. We say that saliva contains an enzyme capable of digesting starch and we generally call the enzyme *ptyalin* but we are speaking of something which is known to us only by its action and not by its appearance. Since the water, salts, and mucus of the saliva do not digest starch we are warranted in saying that something else is there which does have this property.

Although we do not know what enzymes are in a strict chemical sense we do know many of their qualities. They are destroyed by heating their solutions to temperatures short of boiling. They are restrained from acting by cold but in this case they are, not, as a rule, prevented from resuming their action when warmed. They are said to be specific, the idea being that one enzyme has but one action. If a digestive juice affects two distinct types of food it is considered to contain two enzymes. We classify enzymes according to the compounds on which they act: protein-splitting enzymes

digest proteins, fat-splitting enzymes digest fats, starch-splitting enzymes starches, etc.

When we compare enzymes with other chemical agents a most striking fact is recognized, namely, that enzymes are not used up in direct proportion to the work they do. If we are pouring hydrochloric acid upon iron filings to make hydrogen gas we know that we must keep adding the acid if we are to continue to evolve the hydrogen. But if we are turning starch to sugar by the action of saliva the amount of sugar formed depends more on the *time* than on the quantity of the saliva. A very small amount of a digestive secretion, containing a much smaller amount of the actual enzyme, can act continuously under favorable conditions and suffer only the most gradual loss of virtue in the process.

The power of an enzyme to carry on a transformation without itself being destroyed might fail to be evident if the trial were not carefully regulated. If the test were made in a flask the reaction would be found to lag more and more until finally arrested. It might be thought that the enzyme had been exhausted. But the real cause of the arrest in such cases is the gathering of the products of the change in the field of operations. If the products can be removed the reaction will be resumed. We must remember that the conditions in a glass vessel must always be much less favorable to the action of enzymes than those prevailing in the alimentary canal. Nothing can escape from the flask or the test-tube while there is the possibility of withdrawing the digestive products from the canal and enabling the change to proceed.

There is a certain temptation to speak of enzymes as though they were living. This is to be guarded against; they are secreted by living cells but all that they do can be explained without assuming that they have life. Yeasts, moulds, and bacteria which are simple living things may work upon solutions in which they are growing very much as enzymes in suitable variety would.

The result is a fermentation and in all probability its course is determined largely by enzymes which the microorganisms develop. But here again the enzymes are not themselves alive in the true sense of the word. The cells of the growing culture are comparable with the cells of glands, sources of enzymes which can outlast the life of their producers. There is evidence that enzymes may be *intracellular*, that they may bear a part in the chemical changes taking place in protoplasm itself. But most of the story of digestion can be told without reference to this possibility.

While the essential part of digestion is chemical there are physical accompaniments that call for recognition. The early observers made much of them and, indeed, it could hardly be otherwise for their chemical knowledge was slight. They emphasized the crushing and grinding of the food by the teeth and they assumed a continuation of such treatment in the stomach and beyond. The mechanical factors in digestion remain interesting but should be regarded as preliminary to deeper seated changes. The salient fact in connection with mastication or any similar treatment of food is that subdivision increases the surface exposed to the juices. This is just as true when an oil is broken into fine drops—emulsified—as when we have to do with solids.

Much that has gone before can be made clearer by considering what kinds of food need no digestion. This is the case with the *simple sugars*, the *dextrose* of grapes and honey, the *levulose* in many fruits. It is also true of the various mineral salts of the diet, so far as they are destined to be absorbed, and of *alcohol*. Any other kind of food can, theoretically, be predigested, but the advanced cleavage products in the case of proteins and fats are not appetizing.

CHAPTER XIV

SALIVARY AND GASTRIC DIGESTION

Before food is placed in the mouth it has, in many cases, undergone some changes which anticipate those which the digestive enzymes are now to carry forward. Many industrial and domestic processes have helped to separate the useful from the useless and to subdivide the food. This is true of the milling of grain. The ripening of fruits and vegetables and the analogous change in meat—these are in the line with digestion and so far as they have advanced they lighten the task which remains to be accomplished.

Mastication.—In the mouth a vigorous mechanical treatment is administered to the food. The lower jaw has a complex movement, up and down, forward and back, and from side to side. As a result of this the food is not merely shaved and sliced (the particular work of the front teeth with their chisel form) but rubbed and ground between the uneven surfaces of the molars. The tongue contributes much to the process of mastication, rubbing portions of the food against the roof of the mouth and constantly altering the position and bearing of those parts on which the teeth are actively at work.

The Saliva.—While the mechanical operation goes on the saliva flows from the ducts of the glands in quantities of which we have little conception. The secretion forms a very large share of what we swallow and so of the stomach contents after a meal. It has been estimated that 3 pints of saliva are produced in a day. The discharge is of a reflex nature but is best placed among those reactions favored by certain states of consciousness which have been called psycho-reflexes.

The saliva assists greatly in making the food manageable during mastication and swallowing. In some animals it seems to have no other service. In others, including man, it is a real digestive juice. The fact has already been indicated that saliva has the power in such cases to convert starch to a kind of sugar.

This power is referred to the enzyme *ptyalin* or *salivary diastase*. If a crumb of bread is held for some time in the mouth and slowly chewed a sweetish taste gradually develops. This is due to the formation of sugar or of incompletely digested compounds, the dextrins, from the starch of the bread. Someone has said that we can thus turn bread into cake. The change made apparent to the sense of taste in this simple way can be followed almost as readily by chemical tests.

When starch is formed in the leaves of plants it is in grains which give evidence of being dense and brittle. Boiling these disintegrates them and gives rise to a paste or, if the dilution is greater, to an apparent solution. It is fair to say that boiling does not digest starch but makes its subsequent digestion far easier. The surface exposure which is so important is almost infinitely multiplied by the destruction of the granules. Saliva makes comparatively slow progress with raw starch but is wonderfully efficient with that which has been cooked.

Starch gives an intense blue color to a test solution of iodine in potassium iodide. If we try successive samples from a mixture of warm starch and saliva we shall find that the color produced with iodine soon shifts through a violet to a red and then fades until the addition of the digesting mixture to iodine does not darken the color of the reagent at all. A series of tests showing such results must be taken to mean that the starch has rapidly disappeared. Another type of test will show that sugar has taken its place. Most sugars are said to decompose the salts of copper while starch does not. A solution of copper hydrate in Rochelle salts (Fehling's solution) may be boiled with starch without

changing color but if it is boiled with the products of salivary digestion it is bleached and deposits a red or yellow sediment of the oxids of copper.

When a cow is chewing her cud we may suppose that there is salivary digestion in the mouth of the ruminant. The average human being is not apt to hold food long enough in the mouth to allow much transformation; the question is, rather, how long saliva can continue to act in the stomach. We can discuss this to better advantage when we have dealt with the motor phenomena exhibited by that organ.

Swallowing.—Food is transferred from the mouth to the stomach by a coördinated series of movements which give an excellent example of the reflex principle in an elaborate form. First, the material is thrust back into the throat by the practical obliteration of the mouth cavity. Then the muscular bands in the wall of the pharynx contract in order from above downward, squeezing the food into the esophagus. At this moment breathing has to be suspended and the passages closed against the possible entrance of food. This is accomplished for the nasal connection by the drawing back of the soft palate, a mobile partition between the mouth and the upper part of the pharynx. The larynx is shielded by being pulled forward under the root of the tongue and, at the same time, has an additional safeguard through the folding down upon it of a leaf-like lid, the *epiglottis*.

The first stages in swallowing are swiftly executed. When the food is once within the esophagus breathing can be resumed and the bolus advances more slowly. It is thrust down the esophagus by a travelling contraction, successive regions of the tube closing in behind the moving mass as one could manipulate a rubber tube with the thumb and finger to send a glass bead through it. A propulsive movement of this sort is an example of *peristalsis*. Careful analysis has shown that the moving ring of contraction is preceded by a zone of ex-

ceptional relaxation. In about 5 seconds from the time the food leaves the mouth it reaches the cardiac opening into the stomach.

When liquid is swallowed the original impulse given by the reduction of the mouth cavity may send it all the way to the stomach through the passive esophagus. It then arrives almost instantly but a peristaltic wave may be expected to follow at the usual slow rate. In many cases the water finds the cardia in a contracted state and is arrested above it until the wave catches up.

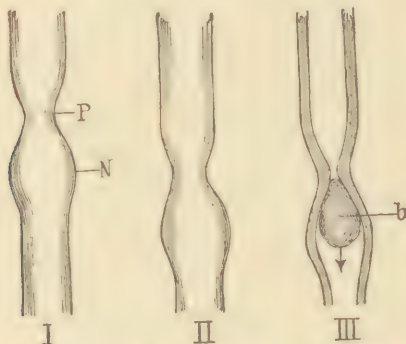


FIG. 47.—An exaggerated representation of peristalsis. I and II are successive views of the same portion of the alimentary tube: *P* is the zone of contraction shifting downward and always preceded by the zone of unusual relaxation (*N*). III is an imaginary section through II, showing the food bolus (*b*) slipping along in advance of the contracting region, its advance being facilitated by the relaxation below.

When the negative, or relaxation, phase of the peristalsis comes along it seems to involve the tissues around the cardia and during the consequent slackening the fluid enters the stomach.

The Movements of the Stomach.—A bird has a thin-walled crop in which food is stored to be delivered slowly to the gizzard. This is a highly muscular organ which contracts rhythmically upon its contents and has its effect reinforced by the gravelstones inside. Man does not have a crop and a gizzard but his stomach is so

differentiated that two regions suggest at least remotely the two contrasted organs of the bird. Food is received at first into the main or *fundic* part of the stomach which is a pouch with rather thin walls. It has for a prominent function the immediate bestowal of a meal. An allied service is to transmit food slowly to the narrower, right-hand part of the stomach leading to the pylorus. This is the region called the *antrum*.

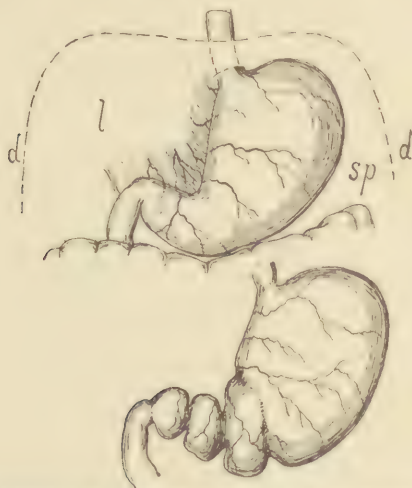


FIG. 48.—Above, the stomach is shown in a distended but inactive state. Below, it is creased by peristaltic waves which thrust toward the pylorus.

The dotted line (*d-d*) suggests the surface of the diaphragm, (*l*) is in the space occupied by the liver, (*sp*) near the position of the spleen. The lesser omentum and the transverse colon are suggested in the upper figure.

The fundus relaxes in an accommodating manner when one is eating. When the meal is secure, it exerts a steady pressure upon it without agitating it to any extent. This sustained pressure insures that, when any of the contents passes to the intestine, more will promptly slip into the antrum. Two hours after a meal the fundus

will be much reduced from its maximum size but will still be pressing with little abatement of vigor upon the material within. This is an unobtrusive action but an important one for the success of digestion.

The antrum is the part which, we have implied, has certain affinities with a gizzard. That is to say, it has a relatively high degree of muscular activity. The circular muscle of its walls is rather heavily developed. This muscle contracts at regular intervals, first near the apparent beginning of the antrum to create a deepening crease in the contour of the stomach; then other circular elements successively are involved and the crease shifts its position toward the pylorus. What is a crease on the outside is, of course, a ring of constriction in the interior. The tendency will be to force small portions of the gastric contents from the stomach to the intestine.

The waves that march down upon the pylorus in this orderly fashion usually find that opening stopped by the tightened condition of the muscle around it. The result is that the matter which is being crowded upon the pylorus slips back through the moving ring. The peristaltic movement is slow but the reflux may be quite brisk. It is probable that people exaggerate the energy of the gastric contractions. They cannot fairly be said to grind or crush the food; the verb often used is "churn" and this may easily lead to a more lively notion of their effect than is justifiable. The safest description is conveyed by the word "mix."

It will be recalled that the smooth muscle which occurs in the walls of the stomach is to some extent automatic. In fact, all the nervous connections of the stomach can be broken and its behavior will be approximately normal. Under such conditions the movements observed are not due to muscular properties alone but also to a kind of local nervous system represented by cells and networks of fibers in the organ itself. The nerves which influence the stomach from without may either increase or diminish its activity

from the prevailing average. Inhibition is seen more commonly than augmentation.

It is most interesting to discover that the tonic contraction of the fundus and the peristalsis of the antrum both may be interfered with as a result of psychic factors. These movements have often been studied by means of the X-rays. (This is accomplished by mixing a substance with the food which will intercept the rays and so image the contents of the stomach as a silhouette on a suitable screen.) It has been proved by repeated observations that the stomach of an angry or frightened animal ceases to work and remains in a relaxed condition until the animal is pacified. The hygienic suggestion is obvious. It will be emphasized later.

Hunger.—When a person has been for some time without food well-marked pangs may be experienced. These are referred to the stomach or to the lower end of the esophagus and they come and go at intervals. These gnawings may be considered to be sensations of hunger as distinguished from appetite. Appetite is a matter of association, involving memories and anticipations; hunger is a simple physical symptom piercing to consciousness and known to infants and to the lower animals as well as to adults. Ingenious experiments have shown that the pangs of hunger are associated with strong contractions of the fundus of the stomach. This may well account for the fact that these sensations are often accompanied by sounds due to the shifting about of gas in the empty organ.

It is probable that the hunger pangs are much more marked in some individuals than in others. In the course of a long fast they become weaker and may cease altogether in two or three days. So it happens that absolute fasting is described as not distressing while insufficient feeding is certainly productive of real suffering. The most harrowing stories of misery endured by Arctic and other explorers have had reference rather to short rations than to downright starvation.

The Sphincters.—Where a circular zone of muscle is habitually contracted to close a passage we say that a sphincter exists. The idea is not so much of a definite structure as of a special manifestation of irritability. We say that sphincters are found at the cardia and the pylorus, meaning that closure at these places is the rule rather than the exception. The conditions which determine whether there shall be contraction or relaxation at these localities have been much studied. Much is found to depend upon the degree of acidity of the stomach contents.

The cardiac sphincter is not so tightly contracted just after a meal as it is a little later. The rustic diner usually concludes his repast by freeing his stomach of the air he has swallowed and has no difficulty in doing so. The X-ray has shown that for a short time after a meal the food eaten by a cat slips out again and again into the lower part of the esophagus to be returned methodically by peristaltic waves. Very soon this escape becomes impossible. The secretion of the gastric glands is strongly acid and the effect of acid acting just below the sphincter is to increase its tone. This is consistent with the fact that a swallow of alkali, such as magnesia or bicarbonate of soda, favors the relaxation of the sphincter and the escape of gas. The central nervous system appears to override the local influence of the acid at the time of vomiting when the opening of the sphincter occurs often in spite of high acidity.

In general, it may be said of the pylorus that it reacts in the same way as the cardiac opening of the stomach. A period of strong closure follows each passage of acid material to the duodenum. The mechanism thus provides that after each transfer of food from the stomach to the intestine there shall be a period of constriction. One cannot picture a simpler or better device to guard against overdistention of the intestine; time is allowed for each succeeding portion to make its way onward before any more follows it.

Vomiting.—When the stomach is to be emptied through the cardia instead of in the normal way the antrum is said to contract while the opening to the esophagus yawns. The diaphragm bears strongly down and the abdominal muscles spasmodically grip the viscera. The sudden pressure projects more or less of the gastric contents up the esophagus. The respiratory passages are protected as in swallowing by the tucking of the larynx under the tongue and the swinging of the soft palate to the back of the pharynx. The chest is alternately expanded and compressed, the expansions enlarging the esophagus for the stomach to fill and the compressions hurrying the accumulation to the exterior. This reflex is one in which the breathing muscles are far more actively employed than those of the stomach. Its value in removing substances that might prove poisonous is perfectly clear but it occurs under many circumstances when it seems to serve no useful purpose.

Salivary Digestion in the Stomach.—The digestion of starch by the saliva is limited by the development of acidity in the stomach. The enzyme of the saliva is destroyed by acid in a minute percentage. The essential question is how long a time may pass before the acidity is developed throughout the mass of the food. This mass, we have seen, lies nearly motionless in the fundus. The incoming gastric juice works its way from the walls of the stomach gradually toward the center. Minute by minute the sphere dominated by the acid will be larger and the core in which salivary digestion can go on will be more restricted. Yet it is likely that for half a hour or more after an average meal some space remains in which starch digestion is in progress.

The transformation of starch by the saliva is now believed to constitute an important part of the digestive process, something which was not held to be true a few years ago. Tests which have been made upon prescribed portions of food swallowed by individuals and recovered after various intervals have shown that a

rather large share of well-cooked starch is turned to dextrins and sugar in the stomach. There is no doubt that the fullest measure of salivary digestion is to be desired since it lessens the work which remains to be done in the intestine and it makes the proteins more accessible to the action of the gastric juice. We must now pass to a discussion of the formation and characters of this secretion.

Gastric Juice.—This is a clear, free-flowing liquid which is furnished at and after each meal by the simple glands in the lining of the stomach. The major part, secreted in the fundus, is strongly acid; the smaller contribution of the antrum is neutral or alkaline. The appearance of the drops of the gastric juice upon the mucous membrane of the stomach is described as like that of profuse perspiration on the skin. The acid is hydrochloric; it must have come from the chlorids of the blood. It amounts to as much as 0.2 per cent. in the human subject and may be somewhat more.

The activity of the gastric glands depends much upon the higher centers. The flow seems to begin in advance of the actual arrival of food in the stomach and to be proportional to the pleasure afforded by the meal. Anger and anxiety, the same psychic disturbances which may abolish the movements of the stomach, may also prevent the production of the gastric juice. We are not likely to overestimate the advantages of attractive food and congenial society about the table.

Skillful experiments upon dogs have shown that it is only necessary for the animals to taste and chew food to have a lively secretion of juice. The morsels swallowed may be diverted to come out through an opening in the neck and thus never reach the stomach, yet the gastric glands are active as long as the dogs are entertained. Human beings who have had artificial openings made into the stomach on account of permanent obstruction of the esophagus still find it beneficial to take samples of their food into the mouth and to dwell upon

their agreeable qualities. The paths of the impulses which go from the brain to the stomach at such times to excite the secreting cells are in the vagus nerves.

Some foods which are of the highest nutritive value—eggs, for example—may be introduced into the stomach of a dog and no secretion will start if the dog has not had the opportunity to enjoy the meal. This by itself might lead to the belief that no gastric juice is produced except under the stimulus of pleasure but this is not actually the case. Some foods produce the reaction by their effect on the lining of the stomach. This has been shown to be true of meats. It is claimed that the dextrins formed in salivary digestion have the same desirable action.

Compounds which have the power to excite the gastric glands directly are known as *secretagogues*. We are quite sure that meat contains bodies deserving this name but there is much disagreement concerning the right of other things, such as alcohol and condiments, to the title. If the dextrins are secretagogues the fact is of interest because it indicates a connecting link between the salivary and the gastric process. A successful salivary digestion would prepare the way for an adequate gastric secretion. Foods, like eggs which contain no secretagogues when undigested, are thought to yield something of the kind when their constituents have undergone some cleavage in the stomach.

Summarizing the causes of gastric secretion we may say that it is induced (1) by pleasurable feelings or (2) by certain stimulating substances in the food. Whatever the means by which it is at first excited it is maintained in the later hours of the gastric digestion by secretagogues arising as by-products of the process itself. The formation of such compounds will cease only when the stomach is empty, so the continuance of the flow until that time is assured.

Functions of the Acid.—The hydrochloric acid of the gastric juice is necessary to the type of digestion which

that juice effects. We have seen that it has much to do with the regulation of the two sphincters. We shall find later that the awakening of the pancreas to activity at a proper time depends to a great degree upon the amount of this acid. Still another function is expressed when we say that the acid makes gastric juice antiseptic. The microorganisms which may have been swallowed in the food are not all killed by the secretion but many of them are while others are probably weakened. It is likely that many germs which might cause disease are destroyed in the stomach. The suggestion has been made that infected drinking water is more dangerous than similarly infected food because water alone induces only a slight flow of gastric juice.

Rennin.—Gastric juice has one curious property which has been familiar from ancient times. This is the power to curdle milk. Extracts made from the lining of the calf's stomach have been used for ages in making cheese. Under the influence of such preparations the bulk of the protein in milk, the *casein*, is changed from a soluble to an insoluble form. This is opposed to our general conception of digestion as a process in which the solubility of the products is steadily increased. The curd has later to be resolved like any solid food. No satisfactory reason for the existence of the coagulating agent can be offered. An enzyme is assumed to be responsible and it is called *rennin*.

Peptic Digestion.—The chief action of the gastric juice is upon proteins. These compounds have been briefly characterized in Chapter II. They are present in most foods but most abundantly in meats, eggs, milk, legumes, and cereals. In the last two classes of staples they are associated with starch. The greater part of the proteins we eat are in a solidified or coagulated form as a result of heating. The effect is familiarly observed in the boiling of eggs. Whether coagulated or not they require extensive digestion and this is begun

by the gastric juice. The enzyme is generally known as *pepsin*. An acid medium is essential to its action.

Solid proteins, like boiled white of egg, first swell in gastric juice and then dissolve. If the sample is originally liquid, like raw white of egg, the change is just as definite though it cannot be followed by the eye. Various stages in the digestion have been described by investigators but they need not concern us. The products which we may expect to find in the place of the original protein after the usual period in the stomach are highly soluble, fairly diffusible, and bitter. They are spoken of as *peptones*. They are susceptible of further cleavage but this is more likely to be accomplished in the intestine than in the stomach.

Fat Digestion in the Stomach.—There is little change in a pure fat, like butter or lard, during the time that it remains in the stomach. Emulsified fats, like cream, are acted upon to a limited extent, the products being glycerin and fatty acids. The enzyme to which this effect is credited is called *gastric lipase*. It is certainly much less important than the lipase from the pancreas which is to reach the food in the small intestine. What we call the fat of meat is really something more than fat in the strict sense. Fat is there in abundance but it is retained by envelopes and fibers which are of a protein character. The supporting material of the adipose tissue is subject to peptic digestion and when this is accomplished the true fat separates as an oil which the gastric juice scarcely attacks.

Fermentation in the Stomach.—Emphasis has been placed on the antiseptic virtue of the gastric juice. The normal acidity prevailing after a meal is unfavorable to most types of bacterial activity, but it is natural to expect that if any kinds of organisms are permitted to multiply they will be those which produce acid by their own life-processes. There is usually some bacterial decomposition going on in the stomach, affecting principally the sugars, and yielding *lactic acid* as a chief

product. This is very like what takes place in the souring of milk, and, indeed milk may be soured in the stomach within a very short interval. Lactic acid is not harmful unless in uncommon amounts; many people who make use of buttermilk or other beverages containing it believe that it is beneficial.

Summary.—The stomach serves, first of all, as a place for storage and to maintain a gradual delivery to the intestine. The antrum has an action adapted to promote the mechanical reduction of the food. Salivary digestion of starch proceeds in the stomach until the acidity is everywhere established. True gastric digestion affects proteins chiefly and is incomplete. There is some digestion of well-emulsified fat. The mixture passing the pylorus two or three hours after a mixed meal may be expected to contain peptones derived from the proteins, dextrins and sugar from the starch, traces of glycerin and fatty acids from fats, portions of all the foods undigested, hydrochloric acid from the gastric juice, and lactic acid produced by fermentation. Except for particularly resistant particles it will be smooth and creamy.

CHAPTER XV

INTESTINAL DIGESTION. ABSORPTION

The three secretions which enter the intestine are all alkaline. It does not follow that the contents will be alkaline throughout for there are sources of acidity to be reckoned with. Three of these are notable: there is the acid received from the stomach, more which is formed by the continued fermentation of sugars in the intestine, and still more formed in the normal digestion of fats. All these acids may react with the carbonate of soda present in the juices and there may be an excess of acid in some sections of the canal. But the average condition is not far from neutral.

Immediately below the stomach the acid material meets the inflowing bile and the pancreatic juice together with some of the succus entericus. When acid reacts with carbonate of soda an evolution of carbon dioxide is to be expected and if this is too abundant to be held in solution there will be an actual effervescence. It has been thought that this may be a useful factor, lightening the texture of the food particles as the gas bubbles in the dough lighten the loaf.

Movements of the Small Intestine.—Four or five hours after a meal the stomach will probably be thrusting out the latest portions of its contents to the duodenum. At about the same time the foremost fractions may be entering the large intestine. It is then that food may be undergoing digestion in every loop of the small intestine while absorption will be at its height. The average rate of progress in the intestine is evidently not more than an inch in a minute. This is vastly slower than the rate of travel in the esophagus which is about 2 inches in a *second*. The mechanical

principle is, nevertheless, the same in the two places. The low rate in the small intestine is due partly to slower muscular action but also to the fact that it is a discontinuous movement; a given collection of food is often at rest for a while.

A peristaltic wave in the small intestine as in the esophagus seems to have two phases, a region of lessened tone running ahead of a ring of contraction. The nervous mechanism of the intestinal wall is capable of actuating peristalsis without the aid of the central nervous system. It may be said of the small intestine as of the stomach that inhibition is more commonly exercised by the central gray matter than augmentation, although both are possible. Where there is an accumulation of food and secretions a peristaltic wave is likely to make its appearance and to push the contents along for some distance, but soon the energy of the propulsion seems to flag and there is a fresh period of rest. The distention of the tube by the food and the degree of tone prevailing in its wall at the moment determine whether or not a peristalsis shall be developed.

Rhythmic Segmentation.—This name is given to a type of movement often seen in the small intestine which does not definitely urge on the contents. A series of tight contractions will appear upon a loop with small, slack pouches between. After a moment there will be relaxation where at first there was contraction and contraction in the intermediate zones which were previously flaccid. The alternation continues for some time and is a relatively brisk action for smooth muscle. Its effect is to slip small quantities of the food back and forth within a short space, mixing them with the juices and shifting their contact with the absorbing cells. The massaging effect upon the blood-vessels and lymph spaces of the intestinal wall may be an important feature of this reaction.

The Fluid Exchanges of the Intestine.—During digestion the secretions enter the canal and the water of which

they are mainly composed is absorbed again in nearly equal volume. We probably have little idea of the amount of fluid thus passing in and out. If all the secretions could be drained away, and not held for the recovery of the water, the daily quantity would doubtless be more than a gallon—perhaps very much more. So long as absorption fairly balances secretion there is no great draft upon the blood and tissues. Such a withdrawal does occur in diseases like cholera and in any severe catharsis.

If, on the contrary, absorption were to exceed secretion, the result would be the concentration of the intestinal contents until the residue might be reduced to a crust upon the walls. This does not occur, at least in any such extreme degree. The balance between secretion and absorption seems most of the time to be nicely struck.

The Pancreatic Juice.—This valuable reagent makes its appearance in the duodenum about the time that the first portions of the gastric contents come through the pylorus. The pancreas, like the glands of the stomach, is subject both to nervous and to chemical influences. But, according to the opinion generally held, the relative importance of the two is contrasted in the two cases: nervous factors are dominant in the stomach while the regulation of the pancreas is more largely chemical. This is rather to be expected, for the activity of the pancreas is not coincident with the pleasure and interest of meals as is the opening work of the gastric glands.

It is reported that the introduction of acid into the duodenum is followed within a short time by the flow of pancreatic juice. The injection of acid into the blood does not have this effect. Hence it has been inferred that the acid, striking into the mucous membrane of the duodenum, produces some new agent which passes through the circulation to the pancreas and acts upon its cells after the fashion of a drug. The agent assumed is called *secretin*. We know that the results are not due to

mere nervous irritation by the acid because it is possible to make an extract from the duodenal lining of one animal (treating it with acid) and to inject this extract into the blood of a second animal which, thereupon, secretes pancreatic juice. Secretin is an example of what we call a *hormone*, a product added to the blood in one place but having its important effects elsewhere.

The juice which flows from the duct of the pancreas plays a large part in digestion. It is customary to say that it contains three enzymes. One of these is a *diastase* or *amylase* closely resembling the ptyalin of the saliva. Under its influence starch may be digested from its original condition or the work may be taken up in the dextrin stages and carried forward. The consequences are practically the same as though the saliva had resumed its action after the interruption suffered in the stomach.

The pancreatic juice contains also a *lipase*, an enzyme adapted to act on fat. Under its influence fats undergo cleavage with the formation of fatty acids and glycerin. At an early stage in the intestinal digestion of fats emulsification, that is, fine subdivision, takes place. This is favorable to digestion, as we have already pointed out, but is not to be confused with digestion itself. There is the possibility in the intestine, not existing in the stomach, that the fatty acids formed may combine with alkali. This is the reaction known as *saponification* or soap formation. It has proved very difficult to say how far it usually goes on.

Tryptic Digestion.—Pancreatic juice, as it comes from the gland, may or may not have the power to continue the digestion of proteins. If it does not have this power at the outset it is destined to acquire it after mixing with the bile and the intestinal juice. These secretions are said to be capable of *activating* the pancreatic juice. The protein-splitting enzyme of active pancreatic juice is known as *trypsin*. It carries along the transformation begun by pepsin.

Trypsin differs from pepsin in two obvious ways: First, it does not require the coöperation of an acid. In fact, acid of such a strength as that in the stomach would destroy the pancreatic enzymes. Second, it is able to advance the cleavage rapidly beyond the stage described as that of the peptones. Thus the usual products of peptic digestion are subject to further decomposition in the intestine before they are absorbed. The simple compounds into which the peptones are at length resolved are best called *amino-acids*. They have been well spoken of as "building stones," for they must evidently be used in new combinations for growth and repair.

The Intestinal Juice.—There is much disagreement as to the properties and importance of this secretion. It is certainly abundant and the general tendency is to attribute to it a larger share in the work of digestion than was formerly granted. It is supposed to change the three common sugars which are not fit for direct introduction into the blood (cane sugar, malt sugar, and milk sugar), into sugars of the simpler order which are acceptable to the body cells. It probably contains the enzyme *erepsin* which coöperates with trypsin in the later stages of protein digestion.

The Bile.—The liver is always secreting bile. It does not have periods of repose like those which seem to be enjoyed by the stomach and the pancreas. But the bile is not always entering the intestine, for there is provision for its temporary storage in the *gall-bladder*. This is a contractile sac lodged in a hollow of the under-surface of the liver. It is so connected with the system of ducts that the bile flowing from the liver may either pass to the intestine or turn aside to gather in the gall-bladder. At another time a large quantity of bile may be expelled from the bladder and introduced into the alimentary canal.

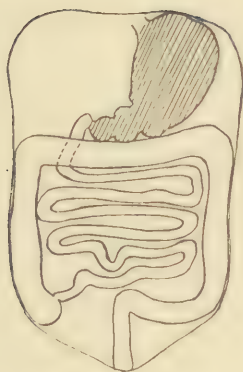
Although the secretion of the bile is always in progress it is accelerated after meals and the hormone, secretin,

is believed to work upon the liver as well as the pancreas. Bile scarcely deserves to rank as a digestive juice. It has little virtue by itself. But it is certain that it creates a favorable environment for the action of the pancreatic enzymes. When it is prevented from entering the intestine, as in ordinary jaundice, the capacity to digest and particularly to absorb food is reduced. This is especially true of fats.

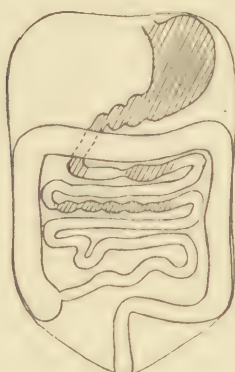
While the presence of bile favors digestion, the secretion contains some constituents which are regarded as wholly useless wastes. This is the character of the *pigments* which give bile its pronounced color. They are chemically related to the red coloring matter of the blood and are undoubtedly derived from it. Two chief pigments are recognized, one which is red and one which is green. The green pigment is predominant in the bile of most animals; human bile varies from green to orange. On the whole it may be said that bile occupies a place intermediate between that of a true digestive juice like the gastric, which is secreted on occasion, and that of the urine which is a vehicle for waste and formed continuously.

The Colon.—The value to man of this part of the tract is dubious. We know that the average rate of progress for its contents is slower than that in the small intestine. During a period which is often more than twelve hours matter received from above is retained in this region. No fresh digestive juice of any consequence is added to it and the changes taking place are mainly induced by bacteria. Some of the products may be available for nutrition if absorbed but others are certainly injurious. A limit is set to the bacterial processes by the drying of the contents which is a marked feature of the interval passed in the large intestine. Whatever questions may be raised with reference to its other uses, it serves as a retriever of water.

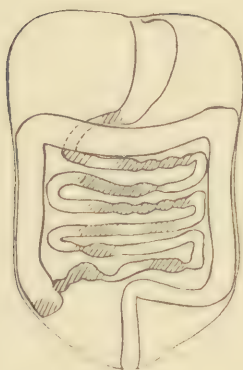
In animals which eat coarse, woody food the large intestine is capacious and probably plays a considerable



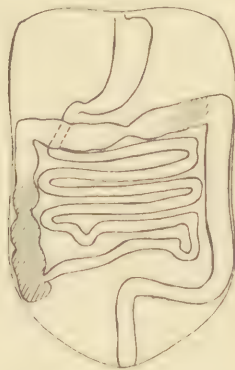
1 P.M.



3 P.M.

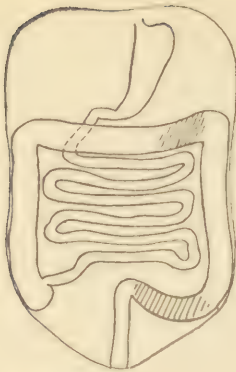


5 P.M.

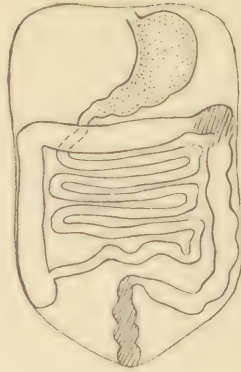


10 P.M.

FIG. 49.



7 A.M.



8 A.M.

FIG. 49.—These figures are intended to show the probable advance of the food during the next few hours after dinner. For the sake of simplicity the tract is represented as free from food taken previously and no supper is eaten. The course of the small intestine is diagrammatic.

At 1 p.m. the stomach is full and active.

At 3 the stomach is smaller, having forwarded part of its contents to the small intestine.

At 5 the stomach is about empty and digestion is in progress at intervals all along the small intestine.

At 10 the small intestine is clear. There is antiperistalsis in the ascending colon. The foremost portion of the material is near the spleen. The mass now consists less of food than of associated secretions.

At 7 a.m. the chief accumulation is in the sigmoid flexure. The lagging part is near the spleen.

Breakfast is eaten, the lower part of the tract wakes to activity at the same time as the stomach, and at 8 the sigmoid has thrust its contents to the rectum. This is the occasion for defecation.

part in digestion. In the rabbit, for example, it begins in a large pouch (*cecum*), usually distended with soft contents undergoing a decomposition which is bacterial in its nature but presumably productive of some compounds profitable to the organism. Such an animal might not absorb nearly so large a percentage of its diet if deprived of the colon. A dog or a cat does very well

without this segment of the canal and so does a man. Enthusiasts have advocated its general abolition but the surgical ordeal is too severe to be courted. Persons who have lost the colon lose a good deal of water but no substantial nutriment in the discharges.

In the lower animals at least, the ascending colon is most of the time swept by waves which run counter to what we are inclined to call the normal direction. They are said to be *antiperistaltic*. The backward thrust tends to keep the food (now called so only by courtesy) packed into the first part of the colon. Its return to the small intestine is hindered by a combination of sphincter and mechanical valve at the junction of the two divisions. At long intervals a strong contraction of the cecum and ascending colon drives a mass of the contents onward as far as the left-hand half of the transverse colon. Here, near the spleen, there is often a period of retention.

When this section of the tube in its turn is aroused to react, a vigorous peristalsis forwards the contents to another place of quiescence, the sigmoid flexure. This portion of the colon is about horizontal when the human body is upright. There is nothing to correspond with it in the quadrupeds and it is looked upon as an adaptation to the erect position. If the human colon were curved like that of a cat any material that passed the spleen might be jarred down into the rectum and distend it disagreeably. The sigmoid receives and bears up the load.

The sigmoid in most subjects thrusts its fecal contents into the rectum about once in twenty-four hours; in many cases this happens with clock-like regularity. The distended rectum at once begins to develop peristaltic waves which the sphincters of the anus at first resist. This strife is attended with discomfort and furnishes the call to defecate. If there is a postponement the rectum may relax and give no sense of fullness. If, however, the time is favorable the sphincters may be relaxed and the rectum emptied by its own contrac-

tions reinforced by the voluntary application of pressure to the abdomen. When this is in progress there may be a transference of more fecal matter from the region of the spleen through the sigmoid to the rectum and this second portion may be evacuated after the original mass.

The Feces.—The waste in the lower bowel is often thought of as a residue from the diet. It may be so in part but when the health is good and the food digestible it consists more largely of secretions. The absorption of food is usually very nearly as good as it can possibly be. Not more than 10 per cent.—often not more than 5 per cent.—of the ration, so far as it has theoretic value, is allowed to escape. It is otherwise, of course, when there is diarrhea.

Anything which is entirely indigestible must naturally be included in the feces. The most important substance which has this character is *cellulose*, the material which is found in the walls of plant cells. Fruits and coarse vegetables furnish it in large amounts. The digestive juices do not appear to attack it; the bacteria of the intestine may decompose it to some extent. Its possible solution is probably of no moment to us so far as the cellulose itself is concerned, but it may be indirectly important since the removal of the envelopes from plant cells may expose the proteins and starch to the action of the juices.

Cellulose is a type of what some writers have called "roughage." It is taught by most authorities that a moderate amount of indigestible matter in the diet is wholesome. It is supposed to stimulate the lining of the canal by its contact and to promote peristalsis. It may be considered to act like the sawdust which the janitor throws upon the floor before sweeping. As the roughage is pushed along the tube it gathers up and takes with it the less bulky but more deleterious wastes. The action might be described as a scouring.

The feces contain enormous numbers of bacteria, living and dead. They also contain mucus and cast-off cells from the epithelium of the tract. The usual

coloring matter is from the bile but modified by decomposition from its original form. The gases of the colon are mainly produced by fermentation processes. The most offensive and doubtless the most poisonous compounds originate from proteins, a fact which suggests one reason for temperance in the consumption of nitrogenous foods.

Absorption.—It may have been gathered from what has been said that the valuable part of the food is removed to the circulation before the colon is reached. This is normally true though the colon has probably some reserve power to absorb nutriment. The small intestine occupies the central position in the process; absorption such as takes place in the stomach is preliminary and that from the colon supplementary. It used to be customary to say that no important work along this line was done by the stomach but that is too radical a statement.

Some absorption of sugar and peptones may occur in the stomach. The organ is, singularly, unable to take up much water. Water taken on an empty stomach seems to pass the pylorus freely and is soon distributed along the small intestine. When water is taken with a meal it is said to slip along the lesser curvature and to take a position in the antrum in advance of the more solid contents. Alcohol is absorbed from the stomach with great speed; it is not necessary to wait for a transfer of the beverage to the intestine to obtain the cerebral reaction.

The small intestine is specialized for the duty of absorption. This is apparent when we notice the extension of its surface. Examination with the naked eye shows that this is increased by the presence of many cross-folds. Under the microscope further evidence of such an extension is gained. The lining is discovered to be thickly studded with eminences, the *villi*. These are finger-shaped processes, rising above the general level in contrast to the glands which sink below it. The arrangement of the villi suggests the bristles in a flat

brush, but their scale is more like that of the nap on velvet. The result of their existence is that the number of epithelial cells in contact with the food is vastly augmented.

The details of the act of absorption are full of difficulty. We cannot deal with them beyond emphasizing

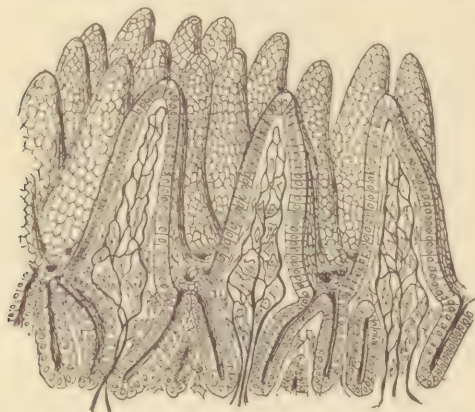


FIG. 50.—Use is made here of a perspective artifice as in Fig. 9. A bit of the lining of the small intestine is shown cut through and extending away from the observer. The eminences are villi with capillary nets inside; the slender pits are glands.

a few points. We are to think of the fluid contents of the intestine on one side of a membrane composed of living cells. On the other side of the membrane is lymph in the spaces of a loosely knit tissue. Blood is moving steadily through the vicinity in capillary vessels the walls of which permit free exchanges. One might expect a certain movement of water and dissolved substances between the blood and the intestine—what is colloquially called a “soaking through.” But this simple conception does not carry us far.

We find that the intestinal lining behaves quite differently from any simple membrane with which it might be natural to compare it. The largest allowance must be made for its living state. Because each of

its cells is endowed with some of the powers of an organism we can say that the epithelium has selective capacity. Energy is probably applied to determine the movement of the various compounds through the cells. Certain bodies which are rated as highly diffusible by ordinary standards are not received through the mucous membrane.

A comparison between grape sugar and magnesium sulphate (Epsom salts) will make clear what is meant by selective absorption. When a test is made with parchment or any inert membrane the sugar is found to diffuse less readily than the magnesium sulphate. The facts are reversed in the intestine; the sugar is absorbed with ease, while the salt is excluded almost entirely from the cells of the epithelial barrier. The purgative action of the salt is due to its failure to be absorbed and to the fact that it keeps back from absorption a large volume of water required to hold it in solution.

The compounds ordinarily absorbed are water, certain salts (especially chlorids), simple sugars, glycerin, fatty acids or soaps, and amino-acids. This statement means that these compounds disappear from the intestine, but it does not strictly follow that they arrive in the blood. There is the possibility of changes affecting them in their passage through the cells. A striking comparison has been made between secretion and absorption. Gland cells take various materials from the blood and often manufacture entirely new compounds which they put out from their free border. Absorbing cells receive sundry substances from the cavity of the intestine and work them over before transferring the resulting bodies to the interior of the villi. Such cells may be said to secrete inward instead of outward.

The best known case of a modifying influence exerted by the lining cells of the intestine is their action upon the products of fat digestion. Glycerin and fatty acids or soaps disappear from the canal but the cells work a change which is the reverse of digestion and that

which enters the lymph, and later the blood, is neutral fat in place of the compounds formed by its cleavage.

The history of the foods after absorption can best be followed when we shall have given some attention to the

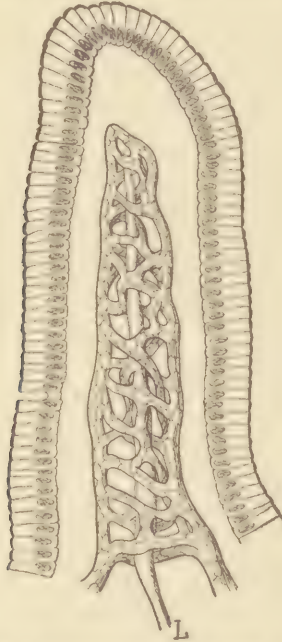


FIG. 51.—This is a conventionalized drawing to show the essentials in the structure of a villus. The lining cells of the intestine are shown as in section. Within is seen a tangle of capillaries, and at the very core of the villus a lymphatic (*L*). The loose tissue, which in reality exists inside the villus, has been ignored for the sake of simplicity.

blood in which they are represented and the main facts of the circulation. It may be well to anticipate one point. Material arriving within the villi must at first be in the indefinite lymph spaces of the tissue. From these crevices it may enter the capillaries—as most of it does—or it may leave the vicinity by pursuing channels of another order, the *lymphatics*. This latter course is taken by most of the fat.

CHAPTER XVI

THE BLOOD

The blood has several well-defined services. It is a carrier of food and of waste. It receives the food from the alimentary canal and bears it away to places of storage or to tissues where it is to be oxidized. It receives waste from the active tissues and transports it to the organs of excretion, especially the lungs and the kidneys, through which it is eliminated. The lungs have a double function since the blood in passing through them not only shakes off the chief oxidized waste-product of the body, carbon dioxid, but gains oxygen in its place.

The blood is also a carrier of compounds which can hardly be classified as foods or as wastes, the hormones. The conception of a hormone has been suggested in connection with the secretin formed in the epithelial cells of the duodenum. A hormone passes from the place of its origin to another locality and modifies the behavior of some organ or tissue. The importance of such agents is more and more widely recognized. Where we formerly believed that the nervous system furnished the principal bonds between different parts of the body we now attribute to hormones many of the influences which clearly proceed from certain organs to others.

One service of the circulating blood which is often ignored is the distribution of heat. The active tissues—those in which oxidation is going on rapidly—must warm the blood which is passing through them. This transmission of heat to the blood limits the rise of temperature in such tissues and the blood imparts some of the heat to less active regions of the body. It also carries heat to the surfaces of the skin and the respiratory tract through which it can be dissipated.

The Quantity of the Blood.—This cannot be estimated by measuring the blood escaping from the opened vessels of an animal, for much will fail to come out. The residual blood may be washed out and the dilution of the mixture estimated. It will then be possible to calculate the original total. Earlier estimates of the blood in the full-grown human body placed the volume at 5 quarts or liters. The recent tendency is to lower figures, 4 liters or 9 pounds being a reasonable assumption.

Plasma and Corpuscles.—We may call blood a red fluid but the color is due to microscopic bodies suspended in a liquid which is, by itself, nearly colorless. The liquid basis is best called the *plasma*. The suspended particles are the “formed elements” or *corpuscles*. It is convenient to call them cells, though the majority of them do not come up to the standard in all respects. If we give them this rank we can look upon blood as a tissue, the intercellular substance being fluid instead of solid.

The plasma constitutes something more than half the volume of human blood. Considering that the corpuscles fill about 40 per cent. of the space in any mass of blood we may well wonder at its free-flowing properties. The solid bodies must be both smooth and elastic to permit such perfect fluidity. The corpuscles are definitely denser than the plasma and in some cases they may subside in a tall vessel until there is a clear layer of plasma at the top from which samples can be drawn.

Blood plasma is a highly complex solution. The most abundant of the compounds in it are the proteins. The plural is used with sufficient reason for there is no doubt that three kinds of protein are present if not a larger number. The significance of these proteins is obscure. Not long ago they were thought to be formed continually in the cells lining the intestine and consumed as food by the tissues in general. But the view is gaining acceptance that they are a rather stable and permanent mass, little subject to depletion and so requiring but little renewal.

Non-protein foods are represented in the plasma but more scantily than would be expected. The sugar is usually not much more than one part in a thousand, while the fat content is higher but still a mere fraction of 1 per cent. The salts of the plasma are kept nearly constant by the reciprocal adjustment of excretion to absorption. The conspicuous one is sodium chlorid or "common salt," the only one which we are at pains to add to the diet. Salts of calcium and potassium are present in very small quantities. It might be thought that their being in the blood was purely accidental and of no moment. This is far from being the case for the removal of either calcium or potassium from the plasma is most disturbing to many of the activities of the tissues.

An interesting suggestion has been made that the salts of the plasma are the same in variety and proportion as those that existed in the prehistoric sea. The simpler marine animals might be expected to have their body fluids based on sea water. Their descendants would inherit this standard of composition. Now the sea water of our age is perhaps three times as concentrated as the blood of vertebrate animals, but geology teaches that it was formerly dilute and must always be gaining in salts as they are washed from the rocks and soil. It is a fascinating thought that races of animals may have more power to maintain fixity in their makeup than the inorganic world around them.

We should naturally examine the plasma for the presence of compounds clearly recognizable as waste-products. These are in fact to be found, but, with one exception, in singularly small amounts. This condition points to an extraordinary efficiency on the part of the excretory organs, especially the kidneys. One waste-product is indeed found in relative abundance; this is carbon dioxid and it is carried both in the plasma and in the corpuscles. We infer the existence in the plasma of many bodies, such as hormones, not because we can detect them by chemical tests, but because the blood has certain actions

for which it is reasonable to assume agents. It is the same with the substances supposed to confer immunity against this and that disease; we do not recognize them directly, but feel that they must be there to account for observed facts.

Red Corpuscles.—The great majority of the formed elements in the blood are red corpuscles. Sometimes they are called *erythrocytes*. The deep red color and the opacity of blood depend on their presence, but these are not evident in the single corpuscle; they result from the superposition of many layers. These corpuscles are individually minute discs with slightly hollowed surfaces. When they are driven on by currents, as in the blood-vessels, they are apt to be cup-shaped, the bulging of the centers showing very clearly the elastic nature of the body.

The size of the red corpuscles in any given animal species is remarkably constant. Most cells vary considerably but these are as uniform as coins stamped by the same die. The red corpuscle of man measures $\frac{1}{3200}$ inch across its face. Its thickness is about one-fifth as great. When blood is viewed under the microscope the enormous number of the corpuscles is at once suggested. It can be determined quite accurately by careful dilution and counting the elements in a small, measured volume. The conclusion reached is that in the original blood there are about 5,000,000 corpuscles in a cubic millimeter (the space occupied by a coarse grain of sugar). The whole number in the body must be something like 4,000,000 times this large number (20 trillion).

When we compare the microscopic appearance of blood from different animals we find that the size of the corpuscles does not correspond at all with the size of the



FIG. 52.—Red blood-corpuscles. Several are shown in different positions. The hollow centers are evident. In one case two corpuscles are overlapped to show that they are transparent. They tend to run into piles, as shown at the right. A saucer-shaped form is represented.

organism. The largest are found in small reptilian or amphibian forms, the smallest in mammals of good size. In general, the corpuseles of the warm-blooded are smaller than those of the cold-blooded types. This appears meaningless until the function of the corpuseles is stated. Their particular service is to absorb, carry, and deliver oxygen. For such a purpose small corpuseles in great numbers must be superior to large corpuseles in smaller numbers. The characteristic of the warm-blooded animal is the high oxygen requirement. Moreover, if the corpuseles are small, the network of vessels through which they are sent can be finely divided and bring them close to all the cells to which they are to minister.

It is the total surface of the red corpuseles which counts in the execution of their specific function. As a result of their vast number and their shape the aggregate surface is well nigh incredible. Calculations have placed it as high as $\frac{3}{4}$ acre for one human being. An able writer has made this area easy to visualize by saying that it equals four baseball diamonds. This does not mean that four diamonds could be covered by the corpuseles from the blood of one man for we are reckoning both sides and allowing for the edges. Still, it is probable that the corpuseles would make a continuous film over a plot of ground 100 feet square. It would be too delicate to redden the surface or to be apparent in any way.

The chief solid in the red corpuseles is called *hemoglobin*. This is a protein and of unusual complexity even for a representative of that class of compounds. In addition to the five elements we expect to find in proteins generally (carbon, oxygen, nitrogen, hydrogen, and sulphur) the red pigment of the blood is exceptional in containing iron. The percentage is low but there is iron enough in the blood of a man to make a small nail. The popular notion according to which iron and "good red blood" are connected has some basis in fact.

Hemoglobin can be dissolved in water or in plasma but it is normally retained in the corpuscles through the agency of their other components. The structure involved is not well understood.

It is hemoglobin which confers on the corpuscles their power to unite with oxygen. The union takes place in the lungs and a temporary compound is formed which is called *oxyhemoglobin*. This is bright red. As the blood flows through active tissues close to cells which are consuming oxygen the corpuscles yield more or less of the oxygen which they have just now attached. In so far as they do this their oxyhemoglobin is changed to what is spoken of as *reduced hemoglobin*. This is blue-black and the more of it there is present the darker the blood. It is not usual for any portion of the blood to give up all its oxygen and so contain nothing but reduced hemoglobin. This may happen in suffocation or, locally, in intense muscular activity. The details are better taken up in the discussion of respiration.

The History of the Red Corpuscle.—It has been said that red corpuscles are not cells in the full sense of that term. It is a question whether we ought to consider them to be alive; perhaps we gain nothing by assuming that they are so. But each corpuscle is probably to be regarded as a modified or degenerate cell and its history is fairly clear. It had its origin in an unexpected locality, the red marrow of the bones. We must make a distinction between this type of marrow and the more conspicuous white or yellow marrow which is found in the hollow shafts of such bones as those in the arms and legs. White marrow is largely fat. The red marrow is found in minute spaces in the expanded ends of the long bones, for example, about the knees and elbows.

Microscopic examination and chemical tests of the red marrow show that it is composed of cells which are rich in hemoglobin. The blood flows among these cells and comes into relatively direct contact with them, since it is not here confined in definite vessels. Those cells which

lie closest to the passing stream are steadily evolved into red corpuscles and when the transformation is complete they detach themselves and drift away in the current. Recent studies make it probable that they cannot do this without passing through the interstices of a membrane. The original cells of the red marrow have nuclei but none can be discovered in the mature corpuscles. The hollow centers strongly suggest the loss which has been suffered. It is a curious fact that after severe hemorrhage, when the system is taxed to restore the normal condition, corpuscles with nuclei are often to be found in the blood. Apparently, at such a time, corpuscles not fully developed are impressed into service.

The evidence goes to show that there is a fairly active formation of red corpuscles and we must suppose that there is a corresponding disintegration. Whether this occurs here and there all over the body or in particular places has been much discussed. Long ago it was maintained that the spleen is concerned in the work of destruction. The view fell into disfavor but has lately been revived in a modified form. Removal of the spleen in certain cases of anemia has proved beneficial, and it is natural to explain such an observation by concluding that the spleen had been destroying the corpuscles more rapidly than the loss could be made good.

It was stated in the previous chapter that the pigments of the bile are derived from the coloring matter of the blood. Wherever the dissolution of the corpuscles takes place we must suppose that certain products are carried in the plasma and sooner or later worked over by the cells of the liver with the result that these waste-substances are separated. It is noteworthy that the pigments of the bile do not contain iron; this element seems to be treated as a precious material which is not to be discarded. It is natural to assume that by far the larger part of the dissolved matter yielded by the decomposing red corpuscles finds its way back to the bone marrow to be wrought into new elements.

White Corpuscles.—When one examines blood under

the microscope it is possible to detect here and there among the host of red corpuscles bodies of a different type. These are the white or, better, colorless corpuscles. There may be one of these to a thousand reds. Several kinds are recognized and the proportion existing between them is of interest to the practitioner. Of all it may be said that they are free from hemoglobin and that they are complete, nucleated cells. We speak confidently of them as living. Some originate along with the red corpuscles in the bones, others in kernels of tissue known as lymph nodes, of which more will be said.

The majority of the white cells are of the aneboid type to which reference was made in Chapter IV. There we indicated the power which these cells have to make their escape from the capillaries and their capacity for devouring bacteria. Other services than this have been conjectured but without very tangible evidence. Thus it has been thought possible that the white cells of the blood have to do with the assimilation and working over of the foods to adapt them to the requirements of the tissues.

Blood-plates.—When blood has been prepared by special methods for microscopic study there may be found in it quite numerous bodies of a smaller size than either the red or the white corpuscles. These are the blood-plates. They were formerly held to be mere particles of débris but the belief is now general that they are perfect though unusually minute cells. They are remarkably perishable and stand in a certain relationship to a curious property of blood, its coagulability. This must be briefly discussed.

Coagulation.—Blood in the vessels is quite free-flowing; it is probably less viscous than is commonly supposed, for we are apt to see it when it is approaching coagulation. The capacity which it exhibits to set into a jelly when shed has a manifest value. It lessens and often completely checks hemorrhage by sealing over the cut surface. There are individuals whose blood does not coagulate and they are in grave danger of bleeding

to death from slight wounds. Their condition is known as *hemophilia* and it is inherited in certain lines of descent. The clotting of blood upon injured surfaces has a secondary function since it gives the basis of the crust or scab beneath which the healing processes may go on.

When blood coagulates in a beaker the whole mass appears for a time as a solid which gradually becomes more tenacious. In the course of some hours it contracts and a clear or but slightly stained fluid exudes. The distribution of the coloring shows that the corpuscles are in the clot and one might infer that the liquid separating must be plasma. It is better to call it by the special name of *serum*. Most of the materials which were originally in the plasma remain in the serum, but there is an important exception: something has been taken from the plasma to knit the corpuscles together and form the clot.

The central fact in coagulation is the generation of a gummy compound which is called *fibrin*. The absolute quantity of this new substance is very small but its physical nature is such that it is capable of changing a liquid to a solid much as gelatin might do. In the absence of corpuscles the clot would have little firmness; they give it body and coherence. We have now to inquire as to the source of the fibrin and why it is formed at particular times rather than at others.

Fibrin is a protein. It is derived from another protein, *fibrinogen*, which exists in normal plasma. Fibrinogen is soluble and therefore its presence does not attract attention; fibrin is relatively insoluble and hence conspicuous in its effects. The formation of the insoluble fibrin from the soluble fibrinogen is an instance of enzyme action and may recall the curdling of milk by gastric juice. The enzyme which causes the fibrin to form and so brings about the coagulation of blood is called *thrombin*. The enzyme comes into existence, or at least becomes effective, under just such conditions as attend the shedding of blood.

The circumstances which hasten and those which retard the clotting of the blood have been studied in the utmost detail. It might be inferred that exposure to air would be an influential one but this can hardly be claimed. Much more important is contact with foreign surfaces, and all surfaces other than the lining of the blood-vessels must be regarded as foreign. When blood flows from a cut, it passes over cells which it does not normally bathe and often over those which have been torn or crushed so as to yield peculiar substances of their own. Then it runs upon the dead skin and perhaps upon clothing or hair. These harsh and extended contacts favor coagulation. Blood will not soon clot in a beaker which has been oiled; this measure seems to create a surface more like the natural lining of the system.

How are we to connect foreign contacts with the production of thrombin and so of fibrin? To make a very long story short we may say that the damaging effect of the strange surfaces is first felt by the blood-plates. As these disintegrate their constituents must pass into solution in the plasma. Agents from this source help to perfect or render effective the enzyme thrombin. The formation of thrombin does not occur in the absence of calcium (lime) salts in the solution and, accordingly, a simple way of warding off coagulation is to remove the lime salts from fresh blood by adding a small amount of potassium oxalate. Other cells than the blood-plates—for example, those of the lacerated tissues outside the vessels—may contribute compounds favorable to the coagulation process.

From what has been said it will be anticipated that clotting may take place in the vessels if conditions arise there which cause the destruction of blood-plates. An injury to an artery or vein, as by tying or clamping, may render the lining so abnormal that it is equivalent to a foreign surface. Fibrin formation will then begin and the clot will build up upon the injured area as a founda-

tion until it may block the channel. The obstruction of a blood-vessel may be fatal if it is in the brain or the heart but in many cases it has no serious results. This is because most parts of the body are not dependent upon single sources of blood-supply.

Sometimes a clot formed in one place is later detached and moves to another locality where it may do more damage than it did in the first region. Thus during convalescence from pneumonia there is the ugly possibility that blood-clots from the temporarily obstructed veins of the lungs may work loose and be carried away in the stream. One of these may reach an important artery of the brain and by stopping it cause sudden death. The course followed in such instances will be more clear after the next chapter.

CHAPTER XVII

THE COURSE AND PHYSICS OF THE CIRCULATION

To serve its various functions blood must be kept in motion. The pump which maintains the flow is the heart and the flow itself is called the circulation because the blood is sent out only to return again and again. In warm-blooded animals the heart is divided into right and left halves and is best thought of as a pair of force pumps making simultaneous strokes. On either side there is a chamber above called an *auricle* which receives incoming blood and transmits it to a second chamber below called a *ventricle*. The ventricles are the chief features of the heart from the standpoint of energy evolved and applied to driving the blood.

Vessels which conduct blood toward the heart are called *veins*. It will be seen that they lead more or less directly to the two auricles. Vessels which carry blood away from the heart are called *arteries*. They are derived from the ventricles, the smaller ones springing from the larger. If we trace the course of the blood along the veins we find it entering larger and larger channels formed by the union of those which are more slender and more numerous. If, in the same way, we follow the blood in the arteries we find it introduced into more and more numerous but finer branches. Both systems are tree-like, but in the veins the flow is from smaller to larger and in the arteries from larger to smaller divisions.

Blood which goes out from the left side of the heart will return next to the right. The arteries which are supplied from the left ventricle empty into veins which lead to the right auricle. The connection between the

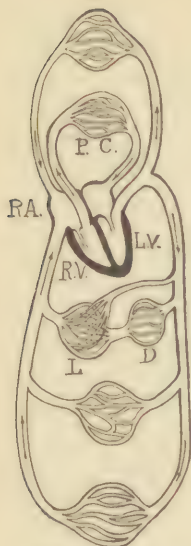


FIG. 53.—In this diagram, as is usual in such cases, right and left are reversed. This is as though the observer were looking at another subject. The short pulmonary path is to be traced from the right ventricle to the left auricle (*P. C.*). Alternative routes are suggested for the passage of the blood through the greater circulation from the left ventricle to the right auricle. The blood which traverses the digestive tract (*D*) passes through a second set of capillaries in the liver (*L*) before it can return to the heart. Note that the liver has in addition a separate arterial supply of blood.

smallest arteries and the finest veins is through the *capillaries*, microscopic channels with the most delicate enclosing walls that can be imagined. A capillary may not be much wider than a single red corpuscle. But as these vessels are the narrowest of all they are likewise by far the most numerous.

The left ventricle sends blood to all parts of the body. When it comes back to the right side of the heart it has parted with some of its oxygen in the service of the tissues. The right ventricle sends it to the lungs. In these organs the corpuscles are freshly charged with oxygen and some carbon dioxid is discharged. The blood is returned to the left side of the heart and is ready to go out again to sustain the activities of the various systems. The arrangement is such that every corpuscle which has made the journey from the left side of the heart to the right is compelled to pass through the capillaries of the lung tissue before it can go anywhere else.

It is somewhat different with cold-blooded animals. These have but one ventricle. Blood goes out from it and is sent in part to the body at large and in part to the lungs or gills. Only a fraction of the blood is fully oxygenated. But this fraction reenters the heart and raises the average composition of the mixed blood. Thus a standard is maintained which is ade-

quate for the support of life in such animals but inferior to that required by the warm-blooded.

The blood that is traversing the body in general on its way from the left side of the heart to the right is said to be in the greater or *systemic circulation*. That which is passing from the right side of the heart back to the left by way of the lungs is said to be in the lesser or *pulmonary circulation*. More than three-quarters of all the blood is probably in the systemic circulation at any given moment. But it is also true that the two ventricles pump out equal quantities of blood in equal times. Students often find difficulty in reconciling these two facts, but there should be none. It is only necessary to reflect that no more blood can be pumped out from either ventricle than the other ventricle supplies to it. The service of the left ventricle is much heavier than that of the right. It has no more blood to drive forth into the arteries at each beat but a much greater mass, upon a longer journey, has to be kept in motion.

There is a somewhat unfortunate difference between the accepted significance of the nouns artery and vein and that of the adjectives arterial and venous. Arteries and veins, as we have indicated, are distinguished by the direction of the current within them with reference to the heart. But the adjective arterial, applied to blood, means "fully oxygenated" while venous means "deficient in oxygen." The systemic arteries carry arterial blood but the pulmonary arteries contain blood which is venous. The systemic veins convey venous blood while that in the pulmonary veins, having just left the lungs, is arterial.

Arteries are elastic tubes of great strength. Their walls are of considerable thickness. An important feature of the smaller ones is a marked development of muscle of the smooth variety. Veins are less elastic than arteries, less muscular, and more capacious. An artery is approximately circular in cross-section, while a vein is apt to be elliptic. It follows that any

unusual pressure inside a vein will round it up and greatly add to its capacity. It has been said that the capillaries are composed of one layer of the thinnest kind of epithelium; this same tissue is continued as a lining through the arteries, the veins, and the cavities of the heart. If all the connective and muscular tissue could be removed from the circulatory system it would be quite completely mapped in epithelium of inconceivable delicacy.

The Velocity of Blood-flow in Vessels of Different Classes.—Before we analyze the action of the heart we will consider the main facts about the progress of the blood through the vessels. The left ventricle thrusts it first into the great main artery, the *aorta*. This rises above the heart, arches over, giving off branches to the head, arms, and chest, and then sweeps down in front of the spinal column. It pierces the diaphragm and supplies the abdominal organs, the trunk muscles at this level, and finally the legs. The blood advances along the *aorta* at a high velocity. In one second a corpuscle may move from the root of the vessel to a point as much as 12 inches away. In all the large arteries the blood moves rapidly, but nowhere so fast as at the very beginning. The student is apt to leap to the conclusion that the aortic velocity is maximal because the blood is there under the unspent impetus of the heart's contraction. This is a wrong notion as will be shown.

The rate of flow in the capillaries can be observed directly with the microscope in various transparent structures, such as the mesentery. It is very slow. A corpuscle is likely to take fully a second to traverse a capillary $\frac{1}{25}$ inch in length. Such a velocity is not over $\frac{1}{300}$ of that in the *aorta*. It has been set as low as $\frac{1}{800}$. In the veins we find the blood speeding up and attaining a rate which is not much less than that in the arteries. The highest speed anywhere in the systemic veins is probably in the two large veins which lead nearly all the blood into the right auricle. These are the *venæ cavæ*, the

superior draining the head, arms, and chest, and the inferior the rest of the body.

Why does the velocity fall from a maximum in the aorta to a minimum in the capillaries and then augment again along the course of the veins? The underlying principle is simple if the student will not allow himself to be led away from it. It is merely that in any stream the velocity is greatest where the cross-section of the channel is least and lowest where it is greatest. When the application is made we find that we are required to regard the aorta as the narrowest and the capillaries as the widest part of the system. This is not readily admitted until the enormous number of the capillaries is emphasized. It is not a few capillaries but millions combined which we have to compare with the aorta. It appears that if the united section of all the capillaries were represented by a circular opening in a wall this would be nearly, if not quite, large enough to crawl through! It seems to be a general truth that when a vessel forks the sum of the cross-sections of the branches is greater than that of the parent stock. So if an artery divides the velocity will be reduced while there will be a quickening at the point where two veins unite to make one. If the velocity in the veins never equals that in the aorta it is simply because the two venæ cavae have unitedly a somewhat larger cross-section than the great artery.

The Facts of Blood-pressure.—A vein is easily flattened under the finger; an artery offers a strong resistance. We have here the sign of a great difference between the pressure exerted by the blood in the two vessels. The difference is shown still more strikingly when an artery and a vein are cut; the blood springs from the artery in a pulsating jet

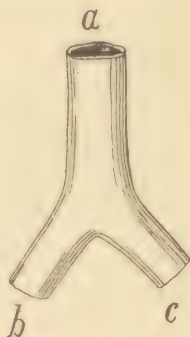


FIG. 54.—If a vessel (a) divides into two branches, (b) and (c), these will be individually of less cross-section than the main trunk but unitedly they will exceed it. Linear velocity will be lower in the branches than in the parent stock.

while the flow from the vein is copious but easily checked. We say that arterial pressure is high and venous pressure low. The contrast became apparent to the pioneer investigator Hales when he performed a certain memorable experiment nearly two centuries ago.

Hales established a connection between the femoral artery of a prostrate horse and a vertical glass tube 9 feet high. The blood mounted in the tube to a height of about 8 feet. The column then rose and fell by a few inches in the rhythm of the heart-beat and showed other fluctuations but in general remained at this high level. When a vein was placed in communication with a similar vertical tube the blood rose only a few inches above the vessel. We have now to explain the high pressure in the artery and the trifling pressure in the vein.

The high pressure in the aorta and its branches is an indication of the power which the contracting ventricle has impressed upon the blood. If we find a liquid passing along a tube we must conclude that, whatever the pressure it exerts at a given point, a still higher pressure prevailed at the source from which it sprang. So if we find blood exerting a great pressure in an artery we have to assume that the pressure was still greater in the larger vessel of which this is a branch and highest of all in the left ventricle which gave the initial thrust.

The physiologist of the present day, if he wishes to measure the pressure of the blood in an artery, does not make use of the tall and inconvenient tube of Hales. Instead he introduces a glass nozzle into the vessel and opens communication through this with a U-shaped tube containing mercury. The pressure then forces the mercury down in the arm next to the artery and up in the distant one. A difference of 5 or 6 inches between the levels of the two ends will hold back the blood in the arteries of a dog or cat and the pressure is read in terms of the mercury column, usually expressed in millimeters. A float on the surface of the mercury in the remote arm of the U-tube is commonly arranged to write a record upon a travelling smoked surface (Fig. 55).

We are in possession of the following facts: pressure in the arteries is high and fluctuating, slightly higher in the main trunks than in their branches; pressure in the veins is low and relatively constant. It must be rather higher in the small veins than in the large ones which they unite to form; the fact that the blood flows from the smaller to the larger ones makes this certain. An im-

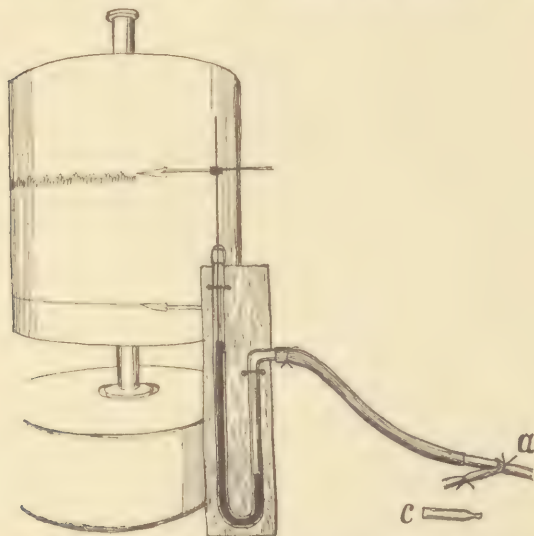


FIG. 55.—The modern method of measuring blood-pressure in animals. A glass nozzle or *cannula* like (*c*) is tied into an artery as at (*a*). The pressure elevates the more distant limb of a mercury column in a U-tube and a float on the mercury causes a writing-point to trace upon a revolving drum. Transmission from the blood to the mercury is by tubing filled with a solution restraining coagulation.

portant inference from all this is that *a great fall of pressure occurs in the region of the small vessels*—the capillaries and the minute arteries and veins immediately adjoining them. This we must presently account for.

We may think of the pressure of the blood as a measure of the energy applied to the blood by the ventricle. What becomes of this energy? In any such system, whether

natural or artificial, it is turned to heat by friction within the stream and along the enclosing walls. Friction is greater at particular places and at these same places pressure will be cut down. The great reduction—"loss of head," as the hydraulic engineer would call it—occurs in the blood-vessels where the extensive subdivision of the stream creates the greatest resistance to progress. In the large tubes, whether arteries or veins, there is little resistance and only a gradual diminution of pressure. When the returning blood nears the right auricle the pressure is scarcely above that of the atmosphere and we may say that the original impetus is spent.

The student finds it hard to refrain from bringing together considerations of velocity and those of pressure which are better kept separate. Note that reduction in velocity means a widening of path while reduction pressure means resistance overcome. Observe also that velocity may increase by the contraction of the channel but we can never find pressure increasing as we follow the direction of the flow in horizontal vessels; it can only decrease. Extra pressure applied at the starting point may indeed increase velocity, but the acceleration will be in all parts of the circuit and it will remain true as before, that the highest velocity is observed where the path is narrowest and the lowest where it has the greatest cross-section.

The Intermittent and the Constant Flow.—The blood is discharged from the ventricles in successive gushes with pauses between. Signs of an intermittent flow are apparent all along the course of the arteries but the character is less marked as the small branches are observed. In the capillaries the onward movement of the blood seems steady and so it does, generally speaking, in the veins. How is the original intermittency overcome? The answer to this question is most easily discovered by attending to the artificial devices which serve a similar purpose. One of these is the air chamber used in connection with force pumps.

This feature may be seen in a fire engine. There is a large dome of metal which contains a quantity of air and is in communication with the channel which conducts the outflow from the pumps. The air inside is an elastic body or cushion. It is under compression to an extent determined by the pressure which is applied to the water by the rapidly working pistons. The tendency of the confined air to expand maintains the discharge during the brief interruptions of the delivery from the pumps. If the air chamber were not provided, the stream sent into the hose would be a pulsatile one.

In the circulatory system there is no large and localized organ to serve the purpose of an air chamber. But the elastic property is represented throughout the arterial tree. The larger trunks, in particular, swell when blood is thrust out of the heart and exert an extra pressure upon their contents in proportion as they are distended. By their contraction when the discharge from the heart ceases they continue the flow in their smaller branches and thus in the capillaries and veins.

Economy of power is secured by the conversion of the intermittent to a constant flow. Much more force would be required to drive the same volume of blood through a rigid system for there would be a dead loss of momentum after every heart-beat and all the blood would have to be started afresh from a state of arrest. This would severely rack the pump. Something approaching this condition occurs in arterio-sclerosis. The hardened arteries of the aged do not yield readily to the inrush of blood from the ventricle. Less of it can be accommodated by lateral enlargement and more has to be pushed straight ahead. This requires the development of greater pressure than would be called for in a more elastic system. Thus the heart is subjected to increasing demands when it is naturally declining in reserve strength. It is one of the gravest of "vicious cycles."

Gravity and the Circulation.—In our discussion of blood pressure we have proceeded thus far as though gravity

were not at all involved. In other words we have treated the subject as though the heart and all the vessels were in the same horizontal plane. This can never be exactly the case and it is very far from the condition in man with his erect posture. In one sense gravity does not influence the circulation: there is always as much blood

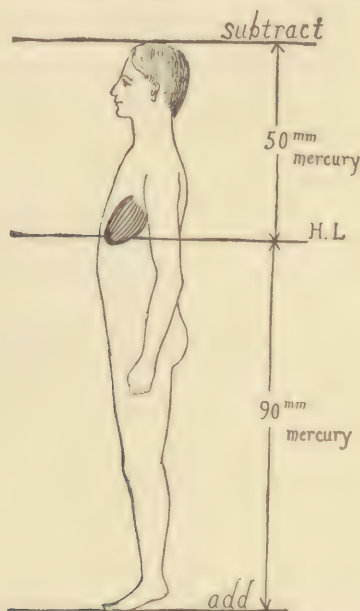


FIG. 56.—To suggest how the weight of the blood-columns adds to local pressures below the heart and subtracts from those above its level. There are obscure factors which somewhat temper the extreme variations. We cannot conclude from a study of this figure that venous pressures in the head and neck are much below the atmospheric. This would be true in a system of glass tubing, but in collapsible veins sufficient pressure must always be maintained to keep the vessels from flattening.

falling as there is rising in the system and we have to do with balanced columns. The heart does not permanently lift any weight from a lower to a higher level. But gravity does have a marked influence upon local pressure.

All blood below the heart presses harder upon the vessels than it would at the heart's own level. All blood

above the heart has a reduced pressure because of gravity. Suppose that a man has been lying down and that the average pressure in the root of his aorta is 125 mm. of mercury. He rises to his feet. The aortic pressure may change somewhat but we will assume that it does not. A moment before the arterial pressure in his head and his feet was nearly equal; now the pressure in the arteries of his scalp is reduced by about 50 mm. and that in his feet is increased by some 90 mm. Still the heart pressure is ample to maintain circulation through the brain and the arteries of the legs are not capacious enough to accumulate much extra blood.

In a three-story house we want to have water pressure enough to provide for a flow on all the floors at once but we cannot avoid having a greater pressure in the basement than in the attic. On the whole it is remarkable that the body can make such changes of position and still be well served by the circulation. When there is faintness, the influence of gravity is distressingly apparent. The usual cause of faintness is an insufficient blood-supply to the brain associated with a failure of the normal surplus pressure in the arteries of the head. It is then of great advantage to lie down and bring these vessels into a position where they are no longer subjected to a handicap.

A most striking effect of gravity is to create an exception to the rule that venous pressure is always low. The blood in the veins of the legs and feet, when the subject is standing, exerts a very considerable pressure upon the confining vessels. In the feet this may approach 100 mm. of mercury, an amount which is almost of the general arterial order. It is not surprising that varicose veins develop in the lower extremities.

The Portal System.—According to our description, as far as we have gone, the blood which is sent out from the left ventricle is forced through one set of capillaries and then returns to the right side of the heart by way of the systemic veins. We must now indicate an important

departure from the type. The blood which is supplied to the alimentary canal (below the esophagus) is not returned directly to the great vein which passes up through the abdominal cavity on its way to the right auricle. This blood, together with that from the pancreas and the spleen, is gathered into a vessel called the *portal vein*. This is unique among blood-vessels of any size, inasmuch as it is made by the union of small branches—like any vein—while it is destined to subdivide again and to supply a set of capillaries as though it were an artery. The second set of capillaries is in the liver.

The blood which has passed through the tissue of the liver is collected by a number of short veins which empty into the inferior vena cava. This circulatory apparatus of the liver is spoken of as the portal system and it will be seen that its chief peculiarity consists in the fact that the capillaries are “tandem” to those of the digestive organs, receiving what may be called second-hand blood. The obvious suggestion is that the liver is interposed between the alimentary organs and the rest of the body to work over the absorbed food principles before admitting them to the circulation at large. The liver receives a secondary supply of arterial blood by a relatively direct channel from the aorta.

The Pulmonary Circulation.—It has been said that the right ventricle has a lighter duty than the left. It has to pump the same quantity of blood in a unit of time but the mass which it has to keep moving is much smaller. The pressure which it is required to develop is not more than a third as great as that which the left ventricle must apply. The blood is sent up from the right ventricle through a short, wide *pulmonary artery* (carrying venous blood). Under the arch of the aorta the pulmonary artery forks to supply the two lungs. The blood comes back to the left auricle arterialized and is brought in by four *pulmonary veins*, two from each side.

The Lymph and its Movement.—The term lymph is usually given to all the fluid outside the blood-vessels.

Some of this fluid is in spaces between the organs and the body walls. Special names like pleural or peritoneal fluid may be used in such cases. Much of the liquid is in microscopic spaces among the cells of the various tissues. Some is in a definite set of vessels, the *lymphatics*. It has been urged that we should reserve the word lymph for the fluid in the lymphatics, call that in the microscopic interstices *tissue-fluid*, and use local names for the contents of the larger cavities. So far as we know the composition of the liquid in these different places is not far from uniform.

Lymph may be thought of as fairly represented by the contents of a blister. The exchanges which take place between the blood-capillaries and the tissues are so free that the lymph must tend to have the same composition as the plasma. It has been roughly described as "blood minus the red corpuscles." As its contact with the active cells is so close we should expect it to contain rather less of the substances recognizable as foods and rather more of those known to be wastes than would be found in the blood. This difference is in fact realized. An exception may be noted in the wall of the small intestine during digestion for here the lymph may be enriched with foods derived from the canal.

The Lymphatics.—These are channels through which lymph flows slowly from all parts of the body toward two places in the thorax where it is introduced into the systemic veins. We ought not to speak of a lymphatic circulation for there are no vessels, corresponding to arteries, through which lymph is carried outward from the chest. The movement is wholly centripetal and therefore comparable in direction with the flow of blood in the veins. We are to think of the lymph as being formed in the tissues and draining away quite gradually to lose its identity at last in the venous blood.

There has been much doubt as to how the finest lymphatics, the lymph-capillaries, begin. Some have thought of them as originating in the indefinite micro-

scopic spaces of the tissues. Others have been led to the view that they come from small sacs bounded by delicate epithelium. But even if the latter conception is correct we may continue to assume that matter derived from the



FIG. 57.—Lacteals and lymphatics during digestion. (Redrawn after Collins.)

active cells can find its way along the lymphatics. The fluid that comes from an organ through the lymphatics may be considered an overflow of plasma from the blood-capillaries, modified by the give and take of the cells which it has bathed.

The great majority of the lymphatics contribute to one chief channel. This is the *thoracic duct*. It is formed below the diaphragm by the union of all the lymphatics from the legs, the pelvis, the abdomen, and viscera. The lymph from the intestine is at times laden with recently absorbed fat. The duct is continued up through the thorax in front of the vertebral column, receiving branches from the chest, left arm, and the left side of the head. It empties at the junction of two great veins, one bringing blood from the left arm and one coming down

the left side of the neck. At the corresponding point on the right there is a rather insignificant lymphatic trunk through which comes the lymph from the right arm and shoulder and the right side of the head.

The thoracic duct in man is perhaps as large as a goose-

quill. If a vein of this size were cut it would yield a large outflow of blood in a short time. By contrast, the flow of lymph from the cut thoracic duct is a mere dribble. The question arises why the lymph flows at all. The fundamental fact is that it is formed under some pressure in the tissues while an outlet into the great veins is provided at a place where there is practically no opposing pressure. It is also permissible to say that the continuous formation of new lymph is bound to crowd along in the lymphatics the fluid that entered them previously.

An important factor contributing to the movement of the lymph is muscular contraction. The larger lymphatics are provided with simple valves which allow an advance toward the thorax but forbid a return. When the skeletal muscles throw pressure upon the lymphatics the lymph is made to slip along toward its distant outlet and when the pressure is removed the refilling of the emptied vessels can occur only from their small branches. There are valves in the veins of the limbs which similarly promote the venous circulation during exercise.

Lymph Nodes.—Lymph which is moving from an extremity toward the thorax must pass somewhere on its way at least one of the structures known as lymphatic glands or, better, as lymph nodes. These are small kernels of fairly dense tissue interposed in the course of the lymphatics, particularly in the abdomen, the neck, armpits, and groins. Microscopic study shows that they must act mechanically as filters, the lymph working through their narrow interstices. Certain cells from these nodes may become detached and pass on with the lymph to the blood, furnishing one type of colorless corpuscle. The lymph nodes probably constitute defenses against the march of infection along lymphatic pathways.

The Circulation before Birth.—The arrangement of the circulatory system in the unborn child is so different from the permanent condition that the changes occurring at birth seem almost miraculous. The critical character

of the emergency and the success with which it is usually met make a story which is too fascinating to be slighted.

The lungs of the embryo are dense and compressed. No air has ever entered them. Their blood-vessels as well as their air passages are nearly closed. But little blood makes its way from the right ventricle to the left auricle through the pulmonary circuit. A temporary provision is made to enable the right ventricle to send out blood in spite of the obstructed state of the vessels in the lungs. The device referred to is the *ductus arteriosus*, a by-pass from the pulmonary artery to the aorta close by. The blood expelled by the right ventricle slips through to join that pumped by the left and the result is that both ventricles are united to supply the arteries of the child.

As little blood passes through the lungs there can be little to enter the left auricle through the four pulmonary veins. But there is an opening through the middle partition between the two auricles called the *foramen ovale*. Through this the left auricle is supplied by an overflow from the right. We have seen that both ventricles deliver to the arteries and now we find that both auricles share the blood returning from the veins. We have next to show how the lack of lungs is supplied. The substitute is the organ called the *placenta*.

The placenta is a disc of tissue rich in blood-vessels which is in close contact with the lining of the uterus. A long cord (the umbilical cord) unites the placenta with the navel of the child. The cord serves chiefly to convey blood to and from the placenta. It contains two branches of the arterial system of the embryo which are derived from the permanent vessels in the pelvis. The blood which is diverted through these vessels is sent through minute spaces of the placenta where it is separated only by the thinnest of walls from the maternal blood in the wall of the uterus. A single, so-called vein comes back in the cord and delivers the blood partly to

the portal vein and partly to the inferior vena cava of the embryo.



FIG. 58.—A conventional diagram of the circulation before birth (compare with Fig. 53). Spatial relations are ignored. It will be seen that both ventricles pump into the arteries, that a diversion of blood takes place to the placenta (at the right of the diagram) and that the returning blood may enter the portal vein or the general venous system. What is less clear is the filling of the left auricle from the right, indicated by a dotted arrow.

The usual distinctions of arterial and venous blood cannot be made in this case. The blood is nowhere up to the arterial standard of the mother. The best of it

is that which has been improved in the placenta by effecting exchanges with the blood in the uterine vessels. This is introduced into the veins of the child. The stream is sufficiently abundant to keep the average composition of the blood suitable for nutrition. The placenta is more than a lung; it is the seat of absorption of organic food and serves for the unloading of wastes. It takes the place, for the time, of the intestine and the kidneys.

At birth, the placental circulation is interrupted. The child is cast upon its own resources and it must begin to use its lungs or perish from suffocation. The stimulus to the medulla to initiate breathing may be due to the rising percentage of carbon dioxid in the blood but it is likely to be reinforced by the effect of strange contacts and an unwonted temperature at the surface of the body. When the first breath is taken the larger respiratory passages are full of liquid. This retreats from the nostrils as the air enters and the compressed system is opened out much as one expands a Christmas bell of tissue paper. The same movement that dilates the air spaces, rounds the flattened capillaries of the lungs and immediately a large share of the blood pumped out by the right ventricle takes its course through them.

The possibility of some crossing over between the two sides of the heart remains for a time but the ductus arteriosus and the foramen ovale are quite rapidly closed. In a few days, in normal cases, no blood can escape going through the lungs after it has journeyed through the systemic circulation. Occasionally there is an unfortunate failure to close the embryonic by-passes and so much venous blood enters the arterial system that a "blue baby" is the result. In such instances the chances of survival are precarious and there is more or less marked malnutrition.

CHAPTER XVIII

THE HEART

The general function of the heart should be clear in the light of what has gone before. It is the double force pump at the center of the circulation. It is conveniently thought of as being about the size of the individual's fist and it is placed in the chest between the lungs.

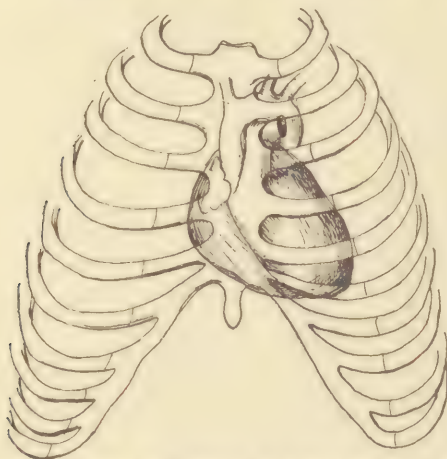


FIG. 59.—Suggesting the position of the heart in the thorax.

More than half of it is to the left of the mid-plane. It is an irregular cone with its apex directed downward, forward, and to the left. This apex comes close to the wall of the chest between the fifth and the sixth ribs, a fact easily remembered in connection with II Samuel III, 27.

The heart is enclosed by a sac called the *pericardium* which is really a continuation of its outer layer, reflected

from the roots of the blood-vessels. In the pericardium is a small quantity of fluid. What we call the right side of the heart is thrown to the front by a spiral twist of the organ so we see chiefly this ventricle when the heart is exposed from in front. The left ventricle is thrown behind but the apex belongs to it; it may be said to be



FIG. 60.—A general view of the heart, the ventricles being cut across to show the crescentic form of the right, appearing like an appendage upon the left.

longer than the right. If the ventricles are cut across it is at once apparent that the left ventricle has the heavier walls. The cavity of the right ventricle in such a section is crescentic and it seems an appendage upon the left. (Fig. 60.)

The heart is supported by the clustered vessels and adjacent structures. The arteries and veins may be recalled: there is the aorta, arching up from the left ventricle, the short pulmonary artery rising from the right ventricle and forking under the arch of the aorta, the two *venæ cavæ* connecting with the right auricle, and the four pulmonary veins entering the left auricle. There is a well-marked groove between the auricles above and the ventri-

cles below. The auricles have uneven contours while the ventricles are smooth.

The cavities of the heart are lined by an epithelium like that of the capillaries. Between this and the pericardium the essential tissue is muscle of the unique order which we call cardiac. The cells are short cylinders united end to end in bundles. The strands which result have a most intricate arrangement; in general it may be

said that they pass spirally around all the chambers of the heart. By their united contraction the cavities are diminished and may be well nigh obliterated, although we cannot assume that this happens at each heart-beat. We are not to think that the solid tissues of the heart lose volume when the act of contraction is performed but the organ externally becomes smaller just in proportion as the blood is pressed out of its ventricles.

The Heart Valves.—As the chambers of the heart are rhythmically widened and narrowed, the blood is driven in a fixed direction. This could not be the case if it were not for the two sets of valves with which the organ is provided. If we speak of those on the left side the description will answer approximately for those on the right. We find a valve between the auricle and the ventricle and another valve or set of valves in the root of the great

artery. The valves are membranous flaps with no power to move save as the currents of blood actuate them. On the left side the valve guarding the opening from the auricle to the ventricle is called the *mitral valve*. Its fellow on the right is the *tricuspid*.

Students often find it hard to remember which is on the right and which on the left. Huxley's mnemonic device may be quoted (without endorsing the statement): "a mitre is a bishop's crown and a bishop would never be found on the right side." The mitral valve consists of two thin and transparent but very tough sheets of tissue

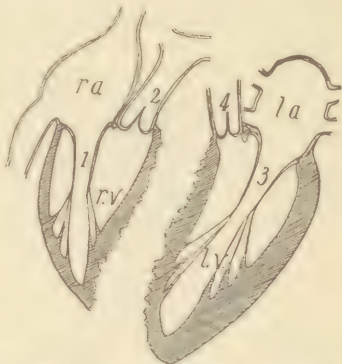


FIG. 61.—For the sake of clearness the two halves of the heart are separated by an interval, (*r.a.*) and (*l.a.*) are the right and left auricles; (*r.v.*) and (*l.v.*) are the right and left ventricles; (1) is the tricuspid, (3) the mitral, (2) and (4) the semilunar valves.

which are directed well down into the ventricle from the edges of the orifice leading from the auricle. They are never far apart but blood can pass down between them freely, while the first sign of a reflux will bring them together. When closure has been accomplished, added pressure in the ventricle will only press the two flaps more firmly one against the other. The lower edges of these flaps are limited in their movement by a number of fine "tendinous cords" leading to the wall of the ventricle.

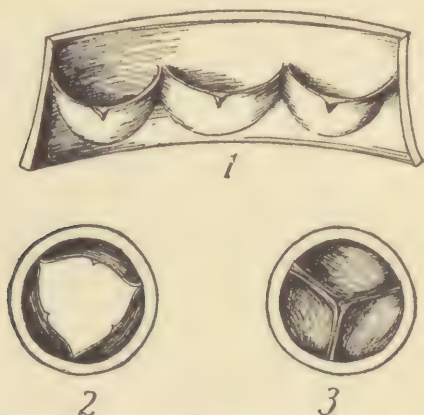


FIG. 62.—The principle of the semilunar valves. At (1) the root of the aorta is laid open and spread to show the three pockets. At (2) we look down into the vessel when the passage is open. At (3) the flaps lie in contact closing the channel.

The valves in the root of the aorta are called *semilunar*. The same name is applied to those in the beginning of the pulmonary artery. In either case dissection shows three pockets on the inner surface of the vessel. Their free borders are directed away from the heart. The passing of the blood-stream in this the normal direction will lay the flaps back against the wall of the artery and there will be a free channel among them. A reversal of the flow will fill the pockets and throw them together, closing the passage. Each flap has, at the middle point

of its edge, a small thorn-like projection, and when the valves are closed these cartilaginous processes are locked in the center of the vessel as shown in the diagram.

The Heart-beat.—By a heart-beat we mean a coördinated contraction of the cardiac muscle resulting in the expulsion of blood from both ventricles. The heart of a man at rest may beat seventy-two times a minute. Some individuals have a lower and some a higher average. The resting rate may be more than doubled by violent exercise. After each beat there is an interval during which the heart is passive. The term *heart cycle* is used to cover the combination of the active and the passive phases, the round of events connected with a single beat of the heart and including the preparation for a succeeding beat. Two old words have survived in the description of the heart action which are almost obsolete elsewhere in physiology: the terms *systole* and *diastole*. The former means contraction and the latter relaxation.

A description of the sequence of events making up a heart cycle may be begun with any phase that we choose inasmuch as we have to do with recurring conditions. It will be convenient to start with the period of general relaxation which, as a matter of fact, lasts about half the whole time. If we assume that the heart is beating seventy-five times a minute we have to assign to one of its cycles 0.8 second. During about 0.4 second in each cycle the heart is not manifesting any active contraction. No blood is being pressed out of it. On the contrary, all its cavities are increasing in capacity and receiving the inflow from the veins.

While this passive condition continues, the mitral and tricuspid valves hang apart and we do well to think of the auricle and ventricle of either side as forming, for the time, a single chamber. The incoming blood may gather in the widening auricle or pass on to the ventricle. If this is clearly grasped the student will be saved from a common mistake: that of thinking that the blood all accumulates in the auricle before any is forwarded to

the ventricle. At the close of the diastolic period the ventricles as well as the auricles are moderately distended.

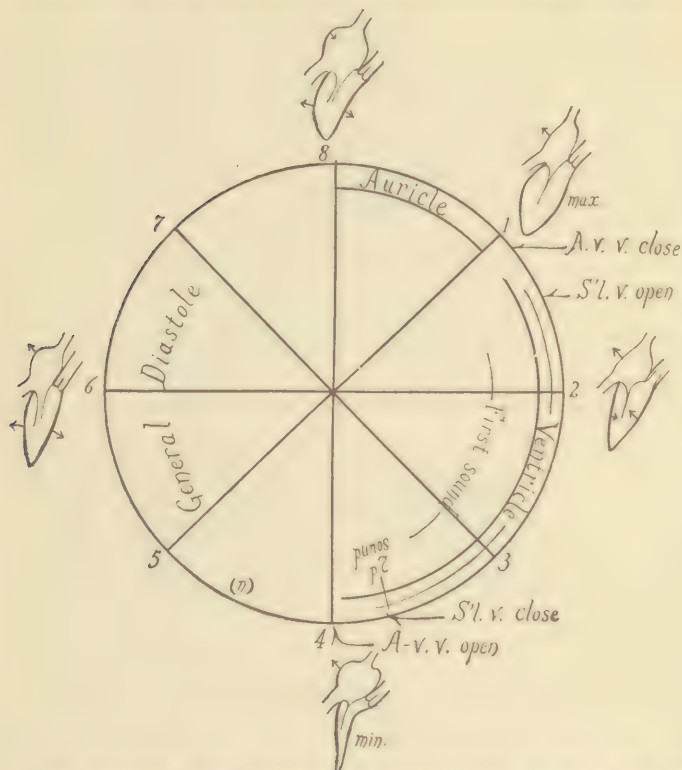


FIG. 63.—The heart cycle. The circumference of the circle is divided into eight parts, each standing for 0.1 second. At (6) the heart is in a passive state and swelling as it receives blood. Between (8) and (1) the auricle thrusts on some blood to the ventricle which reaches its maximum capacity at (1) (max.). Between (1) and (4) the ventricle discharges to the arteries and is reduced to its minimum capacity at (4). While the ventricle is emptying, the auricle is storing blood and is large at (4). The diagram applies to either side of the heart. *A.v.v.* stands for auriculo-ventricular valves, *S'l.v.* for semilunar valves.

The first sign of contraction in the heart is noted in the auricles. Careful observation has shown that there

is a particular spot in the right auricle (the sino-auricular node) from which the process radiates. For the purposes of elementary description we may say that the two auricles contract simultaneously. The systole of the auricles is brief and not at all forcible. Its effect is to transfer a small quantity of blood to the ventricles which are thus put upon a stretch beyond their previous state. As the auricles relax after their momentary contraction, the blood recoiling from the tense walls of the ventricles brings together the flaps of the mitral and tricuspid valves.

It is to be noted that there are no valves to guard the openings by which the veins empty into the auricles. Hence it may be asked why the contraction of the auricles should not turn back the blood in these vessels. As a matter of fact there is something of a check imposed on the flow in the veins of the thorax and neck when the auricles are contracting. But it is only slight because the time of the backward thrust is so short and the momentum of the blood column so great. It is probable that the systole of the auricles has a progressive or peristaltic character, tending to push the blood toward the ventricles rather than in the reverse direction.

When the mitral and tricuspid valves have been closed there is a brief pause. It is an interval during which the excitation is being transmitted from the tissue of the auricles to that of the ventricles. There is a zone between the upper and the lower chambers of the heart in which there is little or no muscle. But a peculiar conducting strand, the *bundle of His*, bridges this region and maintains the physiologic continuity of auricle and ventricle. Through the bundle of His the muscle of the ventricles is presently stimulated and the systole of these chambers follows. This is the essential feature of the heart-beat.

The two ventricles are contracted at the same time. Their systole occupies about 0.3 second under average conditions. The pressure developed quickly rises

to a maximum and as soon as it exceeds the back pressure in the arteries it forces apart the semilunar valves. A rapid emission of blood follows. When the systole of the ventricle wanes it does so with some suddenness; the internal pressure falls below that in the arteries and the incipient reflux of blood closes the semilunar valves sharply. Twice in the course of the heart cycle the ventricles are closed cavities: first, just after the auricular contraction when their content of blood is greatest, and second, when their own systole ends and their volume is least.

The amount of blood thrown from either ventricle during its contraction has been estimated all the way from 2 to 6 ounces. The highest figure is based on the assumption that the ventricle is considerably distended and then practically obliterated. This cannot be assumed and a medium quantity of 4 ounces seems more probable. Pumping at such a rate, one ventricle would put out about all the blood in the body in the course of 40 beats of the heart. This justifies the statement that the average corpusele is sent from a given point—say the left ventricle—around the systemic and the pulmonary circuits and back to the place of beginning about twice in a minute. During exercise, when more blood per minute is needed, the demand is met partly by the quickening of the heart rhythm and partly by an increase in the volume discharged by a single beat.

At the close of the ventricular systole a moderate reduction of the pressure in the ventricle will lead to the closure of the semilunar valves. The pressure must fall much lower to permit the mitral and tricuspid valves to open. But the relaxation is swift and this event follows within a few hundredths of a second. The ventricle ceases to exert any pressure upon its contents and for a brief interval its walls are actually drawing apart with a slight suction effect. The cause of this outward movement will be apparent when we have considered the mechanical conditions in the chest as we shall do when taking up the subject of respiration.

While the mitral and tricuspid valves are closed, the blood brought to the heart by the veins must be accommodated in the auricles. This is in fact one of the distinct services performed by these chambers. When the above-mentioned valves open the auricles are very full and a rapid redistribution of blood between the auricles and the ventricles must take place in the first part of the ventricular diastole, (*n*) in Fig. 63. There are therefore two times in the cycle when the blood moves at an accelerated pace into the ventricles: first when the valves open to admit it from the overfilled auricles and; second, when the active contraction of the auricles thrusts on the latest portion of the ventricular charge.

The Heart Sounds.—Each heart-beat is attended by the production of two sounds which have long been closely studied because of their relation to the recognition of disease. To the trained ear of the physician their subtle variations are most significant. In a book like this we can give them only a little space. The first is described as a prolonged low-pitched and booming note; the second is higher in pitch and has a staccato character. It may be called a click. It can be shown that the first sound occurs during the systole of the ventricles and the second comes at the close of this phase.

It is believed that the first sound, long represented by the syllable "lūbb," has a somewhat complex origin. We have, entering into it, a muttering from the tense walls of the ventricles, the rush of blood through the outlets, and perhaps the humming of the taut valves which are preventing a return to the auricles. If either the mitral or the tricuspid valve is imperfect and there is any considerable reflux from one of the ventricles during their systole the first sound will be altered.

The second sound is usually reproduced by the syllable "dūp." Its origin is quite clear: it is the snap of the semilunar valves as they close at the beginning of the ventricular diastole. It can be reproduced in a lifeless

preparation by injecting fluid backward into the artery so as to throw the valves into contact. Naturally, when there is incompetency on the part of these valves and some blood reënters one of the ventricles during its relaxation the second sound will be changed. It will lose its crispness and be prolonged as a murmur.

In any valvular disease of the heart the obvious result is that more than the normal amount of work must be done to maintain the full volume of the circulation. More or less of the blood slips back and has to be pumped twice instead of once. The extra labor is the same in principle as that which must be performed with any leaky pump when it is required to deliver a certain amount of water. A heart which has to contend with such a condition is exercised and trained like any other muscle and it may act well for many years. Its walls may be much thickened for their heavy duty. But it will be seen that such a heart can scarcely be expected to have as large a reserve power as the normal organ. It is habitually working nearer to its limit.

Some Properties of Cardiac Muscle.—In the foregoing description of the events of a heart cycle but little was said of the contractile tissue at work. We must now make some comparison between this and other forms of muscle. We shall find that in many respects it is intermediate between the smooth and the skeletal types. This is true, first of all, of its microscopic organization. Its cells¹ are short and have each a single nucleus, agreeing in this with those of smooth muscle. But, on the other hand, they are transversely striated somewhat like the skeletal fibers. In speed of movement they are also intermediate; they can work more rapidly than any smooth muscle but they do not equal the skeletal in its capacity to contract and relax quickly.

The most remarkable power of cardiac muscle is its automaticity. We have seen that skeletal muscle seldom

¹ The lines of demarcation between these cells are ill defined and in many respects they seem merged as a continuous structure—a *syncytium*.

contracts unless in response to the arrival of impulses by way of the motor nerves. Smooth muscle shows an automatic tendency and this rhythmic property is most highly developed in the heart. A summary demonstration is obtained when the heart of a frog is removed from the body of the animal. The organ continues to beat. This makes it plain that it does not depend on the central nervous system for the initiation of each beat and we must remember that there is just this difference between the heart action and the breathing: the heart beats of itself while the breathing muscles are thrown into contraction by the brain.

The heart of a mammal taken from the body declines rapidly, though its automatic nature is evidenced by the execution of at least a few contractions. Experiment has shown that the reason the heart of a frog beats longer than that of a cat after its isolation is chiefly that the latter has a greater need of oxygen. If this want is supplied by an artificial circulation of blood, or otherwise, the cat's heart will survive for a long time. It is as truly automatic as the cold-blooded heart.

When the different regions of the heart are compared it is found that the degree of automatic power is not everywhere the same. The rhythmic tendency is more marked in the auricles than in the ventricles. The student must not be confused by the fact that the part of the heart which is physically weaker has a stronger inclination to activity. The ventricles are far more massive than the auricles and do a heavier work but their rhythm is believed to be dictated by these less robust divisions of the heart. It will be desirable to cite certain experiments bearing on this matter.



FIG. 64.—(Cardiac muscle cells (or syncytium).)

Heart-block.—If a thread is tied around the heart of a frog or a turtle between the auricles and the single ventricle, pressure may be applied in the groove until the tissue at that level is seriously injured. It is then usually observed that the auricles go on beating as before but that the ventricle is arrested and remains relaxed. The conclusion might be drawn that the ventricle beats in the normal heart because of rhythmic stimulation passed on to it from the auricles. This appears to be the case. Another conclusion might suggest itself; namely, that the ventricle has no automaticity. This is not justified when all the facts are taken into consideration.

The ventricle will beat without the auricles if it is bathed within by blood or certain solutions which may be substituted therefor. Its rate when beating independently is lower than that of the auricles. Reference has been made to the bundle of His which conducts the excitation from the auricles to the ventricles in the hearts of the higher animals. This bundle may be interrupted by a skillful operation, a hook being inserted so as to pass behind it and then used to bring pressure upon it. When the bundle of His has been disorganized, the auricles beat as before while the ventricles adopt a new and slower rate. A condition has been created which is known as heart-block. The experiment confirms the inference made with the frog's heart that the auricles usually impress upon the ventricle their own rhythm but we see at the same time what could not be made out in the other case, that the ventricular tissue is automatic when the circumstances are favorable.

Heart-block such as can be produced by injuring the bundle of His is supposed to have many points of similarity with a malady known as Stokes-Adams disease. The victim of this disorder suffers at times from inadequate circulation and examination shows that the pulse at the wrist falls during the seizures to per-

haps 30 or 40 beats per minute. At the same moment when the low count is obtained at the wrist the jugular vein may be seen to pulsate 75 times a minute, a normal frequency. Now the throb of any artery corresponds with the beat of the left ventricle while the pulsation of a vein is in the rhythm of the right auricle. Therefore it is clear that in a case of Stokes-Adams disease there is a failure on the part of the ventricles to adopt the pace of the auricles. In other words this is an instance of heart-block.

A somewhat whimsical but useful comparison may be made between the auricle and ventricle on the one hand and a certain type of married couple on the other. We often see a wife of slight physique but great vivacity and ambition who compels a stalwart but naturally phlegmatic husband to maintain the pace which she sets for him. If we pursue the analogy we shall see in Stokes-Adams disease the suggestion of a declaration of independence on the part of the husband, an assertion of his right to take his own time on the way.

It is known, as the result of a great body of research, that the automatic property of cardiac muscle is not exhibited unless the solution bathing the tissue contains certain mineral constituents in definite proportions. This is true whether we speak of blood or of some more simple substitute. The salts most certainly necessary are sodium, calcium, and potassium compounds. The subject is interesting but the details must be sought in larger books.

Another subject which we can do no more than indicate is the question whether the automaticity of heart tissue is a property of the contractile cells or of nervous elements associated with them. Exceedingly small fragments of the organ may carry on rhythmic activity, but it is difficult to be sure that these bits do not contain nervous as well as muscular units. Most physiologists are inclined to believe that the automatic tendency is inherent in the cells of cardiac muscle, but the view that

it resides in intermingled nerve-cells continues to have able defenders.

The All or None Principle.—The bloodless ventricle, or a strip cut from it, may be used to study the response of the local muscle to stimuli just as is done so often with the gastrocnemius. (It will be recalled that the ventricle without blood is not likely to make spontaneous contractions.) When we observe the effect of electric shocks upon the ventricle we note an apparent difference between its response and that of skeletal muscle. The contractions of a skeletal muscle are proportional in height to the strength of the shocks employed to produce them, within a certain range of intensity. The heart muscle, on the contrary, is said to obey the All or None Principle. If any response follows a shock it is a typical, full-sized contraction. We cannot cause the ventricle to execute small beats by reducing the strength of our stimulation to a minimum.

A satisfactory explanation of the difference between skeletal muscle with its graded responses and cardiac muscle with its uniform contractions can probably be given. The cells of the cardiac tissue are so linked that the activity of one excites its neighbors. A disturbance once initiated will sweep through the whole fabric. The fibers of skeletal muscle are, so to speak, insulated and the contraction of certain ones does not tend to bring others into action. It has therefore been urged that the small contractions often made by skeletal muscles are due to the contraction of a small proportion of the fibers, the great majority remaining idle.

Cardiac muscle does not, as a rule, show summation or tetanus when stimulated in a manner which would develop these phenomena in skeletal muscle. Rapidly repeated shocks do not throw the heart into intense and continuous contractions but cause it to flutter. The fact seems to be that whenever the cardiac muscle goes into contraction it expends all its resources for the moment and is bound to relax somewhat while it is re-

gaining power to work again. Hence, after an effective stimulus has been administered nothing is gained by repetition until diastole has set in. The heart is said to be *refractory* toward stimulation while it is in its systolic phase.

The Pulse.—What we call the pulse is a momentary swelling which we notice in an artery. It is associated with the intermittent movement of the blood-stream discussed in the previous chapter, but it stands in such a relation to the heart action that consideration has been postponed until now. The swelling which is felt occurs after each systole of the left ventricle. It is the sign of the transient increase of arterial content due to the introduction of blood from the heart. The lateral enlargement occurs first in the aorta, but is shifted with great speed to all the branches of the arterial tree. In thus shifting along the walls of the elastic vessels the pulse has a wave-like character.

On the surface of a river the ripples may run upstream, across, or downstream and at rates entirely unrelated to that of the current. So, in the case of the pulse, we have to recognize that it travels at a speed which is of an utterly different order from that of the blood-stream. In fact the pulse is propagated many times faster than the blood. A corpuscle may take four or five seconds to run from the semilunar valves to the wrist, but the wave of swelling will pass over the same distance in a fraction of one second.

The physician who feels the pulse with his practised fingers can learn from it not only the frequency and regularity of the heart-beat, but whether the output at each systole is large or small and whether the prevailing average pressure is high or low. Still other signs of the condition of the circulation may be apparent to him. If, for example, the aortic semilunar valves do not close effectively, the pulse is said to have a “collapsing” character, the swelling disappears and the tension is eased with abnormal abruptness.

CHAPTER XIX

THE REGULATION OF THE CIRCULATION

We have treated the subject of the circulation thus far from a mechanical point of view. We have dealt with average conditions as they may be visualized for the human being, and we have said little or nothing of the adaptive changes which take place from time to time. But the reader has learned that adaptive changes are to be looked for in any living system and perhaps they are nowhere more striking than in the heart and the blood-vessels. The facts have been hinted at in Chapter VIII; a fuller exposition is now called for.

The regulation of the blood-flow may be considered under two heads. We must give an account of the influence exerted through the nerve centers upon the heart, and we must later consider the vasomotor mechanism. Under the first head we deal with the total quantity of blood pumped and under the second we attend to its varying distribution.

We have properly emphasized the automatic character of the heart. But we must not ignore the influence of the nervous system upon its rate and force. The heart is like a horse in harness: it is seen to be working at a certain rate and there is no doubt of its independent power to act, but we cannot say that it is doing quite what it would do if left free from all guidance. To destroy the brain is not to stop the heart, but a change in its rate under the circumstances is to be expected. In the same way a horse may go on his way when his driver has fallen from his seat, but a change in his pace is highly probable.

The statement has already been made that the severing of connections between the nervous system

and the heart is most likely to result in a quickening of the beat. This indicates that the prevailing influence of the centers is inhibitory. The paths of the nerve-impulses by which the heart is thus restrained from "running away" are in the two vagus nerves. These nerves have been described as being the tenth pair in the cranial series. They have many other functions besides that of cardiac inhibition, though this is the one the student is most apt to associate with them.

The discovery, in 1845, that the heart is inhibited when the vagus nerve is stimulated was one of the most significant in the history of physiology. It showed that the activity of living tissues can be restrained as well as excited through nerves leading to them. This is a conception which it was most important for the scientist to grasp and it remains to this day unfamiliar to the layman. Cardiac inhibition is quite different from the inhibition of the tone of skeletal muscles which was described in connection with reciprocal innervation (Chapter VI). With the heart it is the contractile substance which is prevented from full activity. In the other case the restraint is applied to certain nerve cells.

The facts of cardiac inhibition were first observed in the frog. The heart of this animal stops beating when the vagus is stimulated and can be kept at rest for an indefinite time. Anyone noting the behavior of the heart for the first time would be likely to infer that the muscle had been thrown into a sustained, cramp-like contraction resembling the tetanus of the skeletal type. That is to say, he would think that the beating of the heart ceased because no diastole occurred. However, close inspection makes it plain that the inhibited heart is in diastole and not systole; it is not prevented from relaxing but from contracting.

Complete inhibition of the heart involves complete arrest of the circulation. This would result in death within a few minutes in any of the warm-blooded animals. But it is scarcely possible to kill a frog or a turtle by this

means. The oxygen requirement of the tissues is so very moderate that fatal asphyxia does not take place either in the heart itself or elsewhere. The heart of a turtle has been held motionless by vagus stimulation for four hours and has resumed beating when the artificial restraint has been removed. When we make experiments upon cats and dogs we find that it is not possible to kill these animals either by inhibition of the heart. Life is preserved through the trial because the warm-blooded heart soon resumes beating in spite of the application of stimuli to the vagus. The heart, in such a case, is said to "escape" from inhibition.

The extent to which the heart can be inhibited varies greatly in different species. In the cat it can scarcely be stopped at all, but it can be slowed and thus its output can be diminished. Perhaps the student is somewhat misled by the striking experiment of stopping the heart. He is to consider that the laboratory trial does not illustrate a normal function but an exaggeration of one. It could never be advantageous to arrest the heart of any animal. So we must think that the true service of the mechanism reached by the vagus fibers is to secure economy and to provide a reserve for emergencies.

The point has been made that the average condition of the living heart is one in which some degree of vagus inhibition is operative. We say that the vagus influence is a "tonic" or sustained one. If this is true, it follows that a heart which is speeding up may be displaying the results of a *withdrawal* of the usual restraint. Its quickening may be like the acceleration of the train on the down grade when the brakes are taken off. The nervous system is not hurrying the heart but merely giving it liberty to make its own pace.

Nevertheless, the heart is provided with nervous connections through which it can be definitely excited to work more rapidly and more powerfully. These connections are the *accelerator nerves* of the heart. They reach it otherwise than by the vagus, and the general

statement may be made that they come from certain ganglia upon the dorsal wall of the thorax. The cells



FIG. 65.—A diagrammatic representation of the heart's nervous connections. (*x-x-x*) is the vagus, descending from the medulla to the abdomen and giving inhibitory fibers to the heart; (*g-g-g-g*) are ganglia of the so-called "sympathetic" chain, supplying accelerators to the heart. Only the nerves in the left half of the body are illustrated.

in these ganglia are under the influence of nerve fibers from the neighboring spinal cord. A skilled operator can pick up slender strands between the ganglia and

the heart and show, by means of stimulation, that it is possible through them to increase the force and frequency of its beating. The effect is not very striking.

Cardiac Regulation. Summary.—The heart has an automatic tendency, particularly localized in the auricles, which would determine its rate in the absence of external influences. But the ordinary rate is not that which the auricles would spontaneously determine. It is considerably slower than this and results from a tonic inhibitory action exerted by the medulla through certain fibers in the vagus nerves. This tonic action may be abated, causing the heart to quicken for a time, and may then be resumed. Finally, there is provision for a moderate acceleration of the heart by impulses following definite nerve paths. It will be seen that it is hard to be sure whether a heart which is quickening its beat is exhibiting the withdrawal of the vagus effect or the active intervention of the accelerators.

Vasomotor Control.—It has been said that the large arteries are essentially elastic tubes while the smallest branches of the arterial tree are well provided with contractile elements. The swelling of large arteries occurs when the pressure of the blood within has been raised and need not be referred to any living characteristic of these vessels. The finer subdivisions (*arterioles*) may contract against a rising pressure or dilate when the pressure is falling. These possibilities exist only because the vessels in question are largely composed of living, contractile tissue. We may compare the large trunks of the arterial system with rubber tubes and not be seriously misled, but we cannot extend the comparison to the arterioles.

The smooth muscle of the arterioles is reached by numerous nerve fibers. Under their influence its tone may be increased or diminished. Such are called *vasomotor* fibers and we often speak of vasomotor nerves. Strictly speaking, what we mean by a vasomotor nerve is usually a nerve in which vasomotor fibers abound;

we cannot ordinarily assume that no other kinds of fibers are present. It will make for clearness if a classic experiment is now described.

More than sixty years ago the eminent French physiologist, Bernard, severed a certain nerve in the neck of a rabbit and witnessed the curious effect manifested in the ear of the animal. If the ear of a white rabbit is held up to the light the red network of the blood-vessels will be conspicuous. Bernard found that a general enlargement of the vessels in the ear followed the cutting of the nerve. It is now known that the nerve operated on, the *cervical sympathetic*, contains fibers which influence the muscle cells in the walls of these vessels.

What interpretation is to be placed upon Bernard's experiment? We believe that the enlargement of the vessels indicates that they were previously held in a state of partial contraction maintained by the constant arrival of impulses from the central nervous system. With the cutting of the vasomotor fibers the vessels were paralyzed, their tone was lost. Very soon after the original observation the complementary discovery was made that electric stimulation of the cut nerve would restore the tone of these vessels and, in fact, reinforce it beyond the normal state, causing the ear to blanch. The fibers whose existence is thus demonstrated are logically called *vasoconstrictors*. The term implies that they convey impulses which make the vessels contract. Such contraction naturally reduces the local blood-supply.

It has become evident since the time of Bernard that vasoconstrictor fibers have a most extensive distribution in the animal body. If a nerve is chosen at random and stimulated, it is usual to see signs of a lessened blood-supply in the region influenced by the nerve. This is most strikingly true in the case of a pair of nerves, the *splanchnics*, which take their rise from certain ganglia at the back of the thorax and pass down through the diaphragm to be distributed in the ab-

domen. Stimulation of the splanchnic nerves greatly reduces the quantity of blood passing through the vessels of the digestive tract. Cutting the splanchnics permits these vessels to widen according to the principle of Bernard's experiment.

If we abolish arterial tone in an important field like that served by the splanchnic nerves we shall greatly lower the pressure in the aorta and its branches. There are two reasons for this: first, the widened vessels oppose less resistance to the onward movement of the blood and, second, the capacity of the abdominal vessels is so much increased that they retain an abnormal quantity of blood, leaving so much less to circulate elsewhere. This has been described as "bleeding into one's own veins" and is a common cause of faintness, for example, in severe indigestion.

Vasodilator Fibers.—The experiment of stimulating a nerve to observe the effect upon the blood flow in its field does not always give the constrictor reaction. We have evidence of the existence of an opposing order of vasomotor fibers through which the dilation of small blood-vessels can be promoted. Such are the vasodilator fibers. If, for example, we stimulate the small nerve known as the *chorda tympani*, an offshoot of the seventh cranial, we may see that the blood-flow through the submaxillary gland instead of being reduced is much increased. The result is explained by the assumption that there are fibers in this nerve which are inhibitory to the contractile elements in the associated vessels.

Students often find it hard to visualize the action of vasodilator fibers. It may be admitted that it is not a simple matter. How can stimulation of nerve fibers increase the diameter of arteries? We shall probably do well to emphasize the fact of the internal pressure in this connection. An artery will dilate if the usual resistance to this pressure is diminished. The chemical changes which occur in the muscle cells under the in-

fluence of the vasodilator fibers are of a paralyzing sort, and the vessel is left free to become stretched by the stream that is being driven through it.

It will now be appreciated that the blood-vessels, like the heart, may be played upon by nerve-impulses having opposite effects. The vagus fibers inhibit the heart; the dilator fibers inhibit the blood-vessels. The heart has accelerator fibers which reinforce its contractile activity and the tone of the small vessels can be reinforced through the constrictor fibers. It should be added that in the case of the heart the inhibitory influence is more in evidence than the opposing one, while the constrictor effect is more prominent than the dilator among the small vessels. Vasodilators do not seem to have a universal distribution. Their existence is best established for the glands, the muscles, the skin of the face, and the genitals.

Vasomotor Adjustments.—We are now in a position to consider some of the adaptive changes made by the nervous mechanisms presiding over the circulation. The great purpose to be subserved is to provide an ample supply of blood to the various capillary areas and to meet the varying demands of different regions. On the negative side we may recognize that economy is secured by restricting the flow through parts where there is no pressing need. The general principle is to increase the supply to any seat of activity, motor or secretory, and to limit the amount of blood sent through tissues which are temporarily at rest.

A local demand, such as may be made by the salivary glands during mastication, may be satisfied by a lowering of the tone in the vessels of these organs and may not entail an appeal to the heart. A widespread need, like that of muscular exercise, requires not only the dilation of many vessels, but a general speeding up of the circulation which can only be maintained by increased heart action. (When vigorous exercise is taken the dilation must extend to the skin as well as the muscles.

The object is to promote the dissipation of the extra heat which is being produced.)

In a later chapter we shall discuss the regulation of body temperature. At this time we ought to point out briefly that the vasomotor system plays an important part in this necessary work. When the surface of the body is warmed a familiar vasomotor reflex leads to the enlargement of the cutaneous vessels and the quantity of blood near the cooling atmosphere is augmented. Under the influence of cold we find that the circulation in the skin is hindered. Moderate cooling of the surface leads to paling. But we must use a little space to comment on the effect of more decided chilling. Everyone knows that this produces a reddening, and it might be supposed that the underlying condition would be the same as that of the skin when flushed with heat. The actual state of affairs seems to be quite different.

Suppose that one hand is held for a while in ice water while the other is in water as hot as can be borne. Both will probably be red, but we can discover signs that the existing conditions are not identical. It will be seen that the veins in the heated hand are swollen while in the chilled hand they are small. The redness induced by cold does not seem to be due to a copious flow of blood through the skin but to a gathering of relatively stagnant blood in the capillaries. The venous outlets appear to be contracted. This is in agreement with the fact that the skin which has been reddened by cold may easily become bluish. The bluish cast is always the sign of an impeded rather than an accelerated circulation.

This illustration makes it convenient to speak briefly of *congestions*. When there is an excess of blood in a part we say that there is a local congestion. But congestions are of two types and fairly exemplified by the states produced by heating and cooling the skin. First, we have the active type in which the arteries are dilated, admitting more blood than usual to the capil-

laries, while there is no hindrance to its free escape through the veins. Second, there is the passive type in which the outstanding feature is the narrowing or the obstruction of the veins. The result is an increased quantity of blood in the capillaries, but it is more or less completely arrested or dammed up. This is the case when cold has had its usual effect on the skin.

We have emphasized the part played by the small arteries in vasomotor regulation. The small veins have a less marked but still noteworthy muscular development and there is no doubt that they have a share in the adaptations. But this is seldom given much prominence by writers on the subject and there is much uncertainty in regard to its extent. The passive congestions of pathology are not due to muscular constriction of the veins so much as to internal accumulations of cells, chiefly white corpuscles. Complete closure of the veins in any region will throw the full arterial pressure into the capillaries, distending them severely and probably increasing the formation of lymph as the fluid filters out into the tissue spaces.

Colds.—What has just been said of congestion is related to our susceptibility to common colds. We speak of taking or catching cold, and it has become probable that there are two senses in which we may do just this thing. A cold is almost certainly an infectious disease; as such one may take it from a previous victim. But we also speak of catching cold when we fix the blame on circumstances under which we have been chilled by drafts or by getting wet. We shall find that the recognition of the infectious nature of colds does not lead to the denial of the other mode of acquiring them.

When the surface of the body is cooled it is entirely normal for the mucous membranes to become engorged with blood. An active congestion, more or less marked, is to be expected. This may result in increased secretion on the part of the nasal lining. But a hardy and

well-conditioned person has a vasomotor system which can be relied on to abate this congestion in a prompt and decisive manner when the external conditions are changed. Another, less highly endowed in this respect, may not terminate the congestion in the nose with such success. It may linger until the tissue is definitely injured or inflamed, when it will tend to become passive rather than active in character.

A passive congestion is always deleterious to the local cell-life. The mucous membrane beneath which the circulation is thus interrupted becomes fallow ground for the growth of microorganisms. There are ordinarily enough of these present to furnish seed for an infection. So a cold may develop which does not appear to have been "taken" from another person. The symptoms may be due to the activity of bacteria, but the occasion for this ebullition of germ life has been furnished by the lowered resistance of the congested tissue.

When we attribute freedom from colds to "vital resistance" our reference may be to either of two conditions. We may have in mind a chemical peculiarity of the blood and other fluids which confers on them the power to destroy bacteria. We are quite as likely to be picturing an organization which is resistant because of its vasomotor efficiency. The hardiness gained by athletic training and cold bathing is probably not a chemical superiority but a mechanical one. The merit lies less in the composition of the blood than in the positive and consistent government of the circulation. Colds are not contracted because incipient congestions are overcome by the vigorous constriction of the arteries immediately after the period of exposure.

The Cranial Blood-supply.—It might seem most difficult to learn anything about the changes taking place in the blood-vessels of the brain. The surface of the cerebrum has sometimes been observed after extensive fractures of the skull, and it has been reported

that the vessels there become less conspicuous in sleep than they are in waking. Quite aside from these rare observations we have some indirect evidence in regard to the brain circulation which is highly suggestive. It throws light not only upon the local problem but upon the general principles of vasomotor operations.

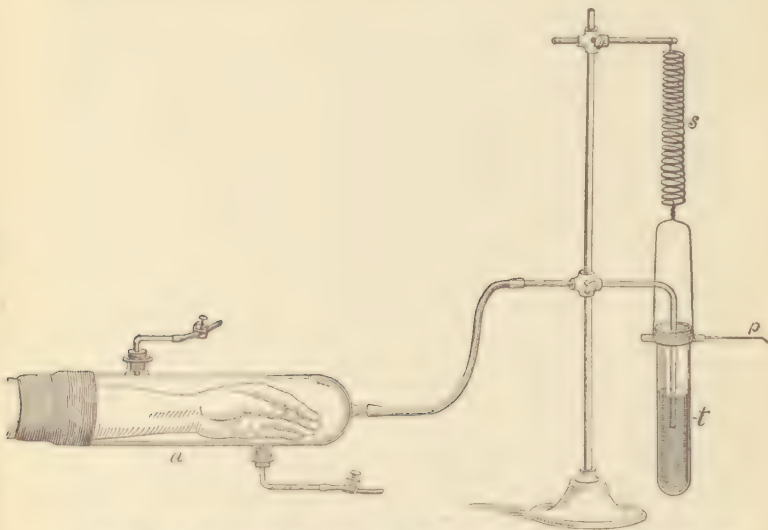


FIG. 66.—A schematic diagram of Mosso's plethysmograph for the arms: *a*, the glass cylinder for the arm, with rubber sleeve and two tubulatures for filling with warm water; *s*, the spiral spring swinging the test-tube, *t*. The spring is so calibrated that the level of the liquid in the test-tube above the arm remains unchanged as the tube is filled and emptied. The movements of the tube are recorded on a drum by the writing point, *p*. (*Howell*.)

It can be shown that when there is a marked change in mental activity there is a vasomotor change detectable in the extremities. Commonly the hand is the part under scrutiny. The instrument used is called the *plethysmograph*. It is simple in theory though quite troublesome to apply successfully. The plethysmo-

graph is a cylinder of glass open at one end and provided with one or two necks with which tubes may be connected. The hand and forearm are introduced into the open end and a water-tight closure is effected around the arm. The cylinder is then filled with warm water. One of the side branches is put in connection with a gage of a sensitive character.

Now if the arm gains in volume, water will be displaced from the plethysmograph and the gage will indicate the occurrence. If the arm shrinks, water will be drawn back and the gage will show the counter-movement. Any quick changes in the volume of the hand and arm may be ascribed to vasomotor phenomena. More gradual ones are less easy to explain -- changes in the amount of lymph would have to be considered as possible factors. The gage of the plethysmograph may be made to write a record on smoked paper and when all is going well the results are of extraordinary interest.

A person who is seated comfortably with his hand enclosed in the instrument may have fallen into a drowsy condition. He is abruptly called upon to answer a question, perhaps to perform a sum in mental arithmetic. As he rallies his faculties and fixes his attention upon the task the record shows that the volume of the limb is notably reduced. The inference is that the nervous system has sent out impulses over the constrictor paths to the vessels of the extremity and so caused them to be contracted. We cannot exactly determine how generally the vessels of the skin participate in this narrowing. Still less can we say whether there is a similar heightening of tone in the internal organs.

If we assume that the act of concentrating the attention is accompanied by vasoconstriction in many parts of the body, we can see that the result may be serviceable to the brain. The contraction of numerous arteries will elevate the pressure in the large trunks and there will be a swifter flow of blood through any vessels

which do not share in the constriction. It is just as though one of two faucets over a sink should be turned off; there would be a reinforcement of the discharge from the one that was left open.

The act of falling asleep is psychologically the reverse of fixing the attention; it is dissipation instead of concentration. It can be shown by means of the plethysmograph that it is also the reverse in its physical signs. Individuals have schooled themselves to sleep with the arm in the plethysmograph and the records obtained show that about the time consciousness is lost, or transformed to that of the world of dreams, there is a slackening of tone in the vessels, an increase of volume in the limb. If what happens in the arm is typical of what takes place elsewhere there must be a lowering of pressure in the main arteries at such a time. Then, if the vessels of the brain do not greatly change their caliber the flow through them will be much reduced. When sleep was under discussion in Chapter XII it was stated that diminished blood-flow might account for its onset.

Of course the act of waking is a resumption of attention. It is known to be attended by a constriction of the vessels in the part observed. Thus all that we know of the adjustments in favor of the brain is easily coördinated and understood. The reciprocal element in vasomotor changes is apparent in other cases besides this. We assume that a dilation of the surface vessels will relieve internal congestion. This is the principle which justifies hot applications. An obvious feature of the reaction to alcohol is the flushing of the skin, and here too we suppose that there is a corresponding withdrawal of blood from the deeper parts.

The Afferent Side.—So far we have spoken of the cardiac and vasomotor nerves as pathways leading from the central gray matter to the organs of the circulation. Little has been said to bring out the fact that they are used in reflex fashion. But the general truth

is always to be borne in mind that efferent nerves carry out from the brain and cord impulses which owe their origin to the previous arrival of other impulses over sensory paths. There is therefore an afferent as well as an efferent side to this mechanism.

A series of light blows rapidly delivered upon the abdomen of a frog may slow or even stop the heart. This is a clear case of reflex inhibition. Impulses run to the medulla and cause the return of others which find their way to the heart along the vagus fibers. In like manner, afferent impulses may reflexly affect the tone of the blood-vessels, either slackening or tightening the arteries. A reflex change in which arterial tone is lowered is called a *depressor* reaction; the contrasted reflex, with heightening of tone, is a *pressor* response. The adjustment made to support the fixation of the attention and demonstrated with the plethysmograph is, accordingly, a *pressor* reflex.

The average aortic pressure is kept sufficient to insure an adequate blood-supply wherever a channel may be opened by vasodilation. It is important that this pressure shall not greatly fall, and it is in the interests of economy and safety that it shall not greatly rise. An elaborate reflex mechanism exists to keep it within reasonable limits. If the pressure tends to mount up, of course one of the direct results will be a stretching of the aorta. But there are receptors in the wall of this great vessel which are stimulated when the high tension is established. Impulses are set up in nerve fibers which lead to the medulla. Reflex responses follow which abate the rising pressure.

The reflexes just referred to are of two kinds. Some degree of inhibition is imposed upon the heart and there is simultaneously a lowering of tone in the vessels of the digestive tract. Thus the high arterial tension is relieved both by easing the heart, and so reducing its output, and by providing for the freer escape of the

blood from the distended arteries to the veins. This is one of the most impressive examples we have of a complex nervous mechanism devoted to the fulfillment of an important function and quite shut away, under most circumstances, from our own intermeddling.

CHAPTER XX

BREATHING

Respiration has been defined earlier in this book as the oxidation process which accompanies life and serves to release the potential energy of the physiologic fuels. In this intimate sense respiration is best studied as a part of metabolism, the chemistry of the living matter. But while the facts of the circulation are fresh in mind

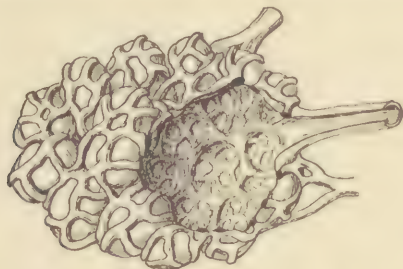


FIG. 67.—A microscopic unit (air-cell) from the lung tissue. The capillaries are wrapped about a sac the form of which may be likened to that of a blackberry. In the drawing this sac is represented as partly laid open and the minute bronchial tube leading to it is slit. The rent shows the concavities of the interior surface.

we shall do well to enter upon a treatment of breathing and the carriage of gases in the blood. Breathing is not respiration, in the best use of that word, but it is preliminary to it and also subsequent to it; it introduces the oxygen into the blood and provides for the escape of the carbon dioxid into the air.

The Respiratory Apparatus.—It has been said already that the lungs are organs in which the practical contact of blood and air can be maintained. The pul-

monary arteries conduct the blood from the right side of the heart into capillaries which are wrapped about minute air-sacs. Two cell-layers are here interposed between the blood and the air. The gases have to pass through the capillary wall and also the wall of the air-sac. But the wall of the capillary is of the utmost delicacy and the epithelium of the air-sac is of the same nature. If the blood actually fell in drops through an air-chamber it would probably be no more thoroughly aerated than it is in fact.

Each lung is to be regarded as consisting of a system of blood-vessels intertwined with vessels containing air. The resulting tissue is peculiarly light and yielding. It is for this reason that the lungs of the lower animals are colloquially called "the lights." If they are thrown upon water they float with a great part of their mass above the surface. The two lungs fill the greater portion of the chest cavity. The left lung has a somewhat smaller volume than the right, chiefly because the heart subtracts space from that half of the thorax. On the other hand, the left lung is rather longer from top to bottom than its fellow. Roughly speaking, the two taken together, with the heart and the connecting vessels, form a cone with its base upon the diaphragm.

The air which we breathe reaches and leaves the lungs by way of the *trachea*. This is a tube extending downward from the larynx which, it will be recalled, is at the root of the tongue and ventral to the upper part of the esophagus. The trachea continues in front of the esophagus to a point within the chest where it forks into branches, the *bronchi*, leading into the two lungs. The trachea and the bronchi have rather rigid walls and are kept open at all times. This firmness is owing to bows of cartilage imbedded in their tissues. The contrast between these carriers of air and the esophagus is marked, for the latter is nearly or quite collapsed unless something is passing through it.

Air may reach the larynx through the mouth or the

nose. The nasal passages occupy a large space in the skull and are extensively subdivided. Scroll-like processes from their walls jut into them and present a much greater surface to the passing air than would be supposed. These processes consist of a bony foundation overlaid with mucous membrane. The blood-supply of the lining of the nose is a liberal one and the cells are constantly secreting moisture. As the air is

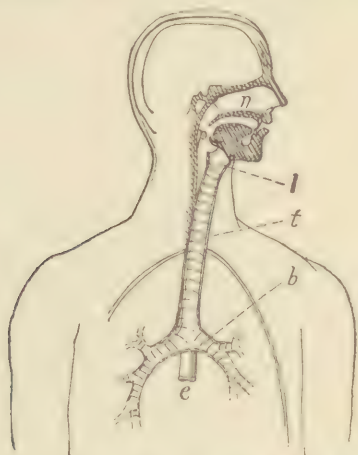


FIG. 68.—The path of the breath. Details of the upper part may be seen to better advantage in Fig. 43. *n*, Nasal passage; *p*, pharynx; *l*, larynx; *t*, trachea; *b*, left bronchus; *e*, esophagus, continuous with the pharynx above.

inhaled it is affected in at least three ways by its contact with the mucous membrane.

In the first place, it deposits a large proportion of the dust particles which it may have brought in. As has been stated in Chapter IV, such particles are removed by ciliary motion—whether toward the pharynx or the nostrils is disputed. In the second place, the air which is usually taken in at a temperature below that of the body is warmed nearly to blood heat in passing through

the nose. Finally, it becomes nearly saturated with water vapor. We may breathe a cool, foggy air which is already saturated and still impart moisture to it for, as we raise its temperature, it gains in the capacity to hold water. The three actions named—filtration, warming, and moistening—are probably better performed by the nose than they can be by the mouth.

The purpose of the breathing movements is to renew the air in the terminal sacs of the lungs. Before we can make clear the means by which these movements are executed certain mechanical conditions which prevail in the thorax must be dealt with. First of all, the fact is to be emphasized that the lungs, like other viscera, are not directly attached to the chest wall. In dissecting a normal animal we find no trace of adhesion between the two pleural surfaces, the one lining the thorax and the other making the exterior of the lungs. The only connection between either lung and the rest of the body is through its bronchus and the pulmonary vessels.

Next we must note the fact that when an animal is dissected the lungs appear much smaller than the cavity which they completely filled in life. They have collapsed and contracted to a half or a smaller fraction of their former size. Sometimes one has a glimpse of the lung in the act of falling away from the body wall as the scalpel goes through it. After their collapse they can be brought back to their normal size by blowing through a tube which has been tied into the trachea, but they will promptly shrink again if the air pressure is discontinued. Yet the force needed to hold them to their full capacity is surprisingly small.

The collapse of the lungs when the thorax is opened is proof that they were always tending to do just this thing—always drawing inward upon the chest wall. As has been explained in Chapter III, actual separation between the organs and the body wall cannot occur unless air or liquid is admitted between them. To part them otherwise would require the immense force neces-

sary to overcome the atmospheric pressure and create a vacuum. Students of physics will recall the Magdeburg Hemispheres. A wound which pierces the human thorax may admit air between the two layers of the pleura and permit the collapse of a lung, giving rise to a condition known as *pneumothorax*. This can happen

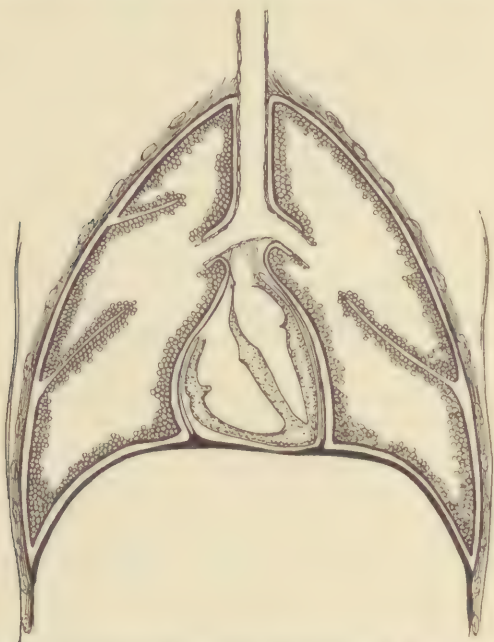


FIG. 69. —To suggest the absence of connection between the lungs and the walls of the chest. (See text.)

to one lung without seriously affecting the situation of the other.

A collapsed lung is practically useless. It no longer follows the movements of the chest as the normal lung does. Instead it remains of a nearly constant volume and the little air which it contains is not renewed. Recovery from one-sided pneumothorax is possible.

One lung serves to keep up respiration for the time and after the wound is closed the air between the chest wall and the contracted lung is gradually absorbed. In proportion as it is removed the lung approaches its full size and at length the layers of the pleura are once more in approximate contact. A lung may be reduced in volume and in usefulness by the accumulation of liquid as well as air outside it and it is sometimes necessary to withdraw such fluid through a puncture between the ribs.

The Breathing Movements.—Generally speaking, any movement which enlarges the chest will enlarge the lungs. The enlargement will affect chiefly the elastic terminal sacs which are much more susceptible to stretching and recovery than the blood-vessels or the *bronchial tubes* between these sacs and the bronchi. When the sacs are made larger air will press into them as into a widening bellows. It is the atmospheric pressure which drives it and not a muscular application like that of swallowing. Any movement which makes space for the reception of air is reckoned a movement of *inspiration*. From what has been said of the elastic tension of the lungs it should be evident that these organs *resist* inspiration and *assist* in expiration. The one is made more difficult than if the lungs were indifferent to it, while the other is facilitated. The condition may be likened to that illustrated by a screen door which has a spring: it is harder to open than if it had none, but it closes itself.

Elevation of the ribs is an important factor in inspiration. It is not necessary to analyze the action of the muscles by which this is brought about, but the effect upon the dimensions of the thorax must be made plain. There are twelve pairs of ribs. Each rib is hinged upon one side of a vertebra. It connects with the vertebra at two points and, this being the case, its movement is limited to rotation around an axis passing through these two points. The direction of the axes is somewhat

different in the case of the upper from what it is with the lower ribs. We will consider first the effect of raising the upper ribs upon the thoracic cavity.

The first rib is a short one, curving with a small radius from its attachment to the first dorsal vertebra

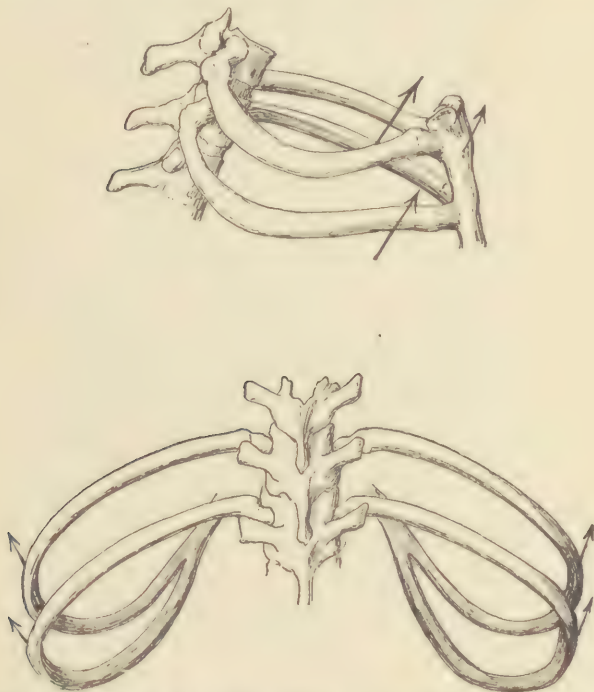


FIG. 70. —Above, the first and second ribs are viewed from the right. To elevate them is to carry forward their ventral ends and the breast bone, deepening the chest.

Below, the ninth and tenth ribs are viewed from behind. As they are raised the chief result is a lateral spreading.

to reach the upper end of the breast bone. The ventral ends of the first ribs are considerably below the dorsal as observed on the erect figure. Their axis of rotation is around a line drawn from right to left across the

vertebral column. If the conditions are successfully visualized, it will be seen that when the first ribs are raised they must carry the breast bone with them and at the same time thrust it forward. The result is a deepening of the upper chest.

As we follow the series of the ribs downward we find that there is progressive shifting in the direction of their axes of rotation. These axes never become quite dorso-ventral (front to back) but they tend more and more toward this limit. Our attention may be fixed upon a selected pair, perhaps the ninth or tenth. These ribs are long and they are attached to the lower part of the breast bone only indirectly and by means of flexible cartilages. Their borders are much lower than their articulations with the spine and lower, also, than their final connection with the breast bone. When these ribs are raised their lateral portions are swung apart to the right and left. Thus the lower part of the chest is widened more than it is deepened in inspiration.

The Diaphragm.—This dome-shaped partition between the thorax and the abdomen has already been mentioned. Its central part is a flat tendon and its borders are muscular, the general direction of the fibers being radial. It is one of the muscles concerning which it is not easy to distinguish origin and insertion. As these terms have been defined, the origin of a muscle is the stationary and the insertion the movable attachment. When the muscle fibers of the diaphragm are thrown into contraction it cannot always be predicted that one part or another will be moved. There are at least two distinct possibilities.

We may picture the margin as fixed. If this is the case the curve of the dome will be flattened and the chest will gain in capacity by the lowering of its floor. The borders of the diaphragm will be bent inward and, with a more intense contraction, there will be an actual depression of the center. The lungs will be stretched vertically, their bases descending. A movement such

as this adds space to the thoracic cavity and it would be natural to say that it must subtract space from the abdomen. But this is not strictly true. The abdominal contents are incompressible, so if the diaphragm is to descend at all it must do so by crowding the viscera out of place and room has to be made for them by stretching the abdominal wall. The abdomen is not made smaller but its shape is changed.

If the descent of the diaphragm is opposed, the chief effect of its contraction may be to pull its marginal at-

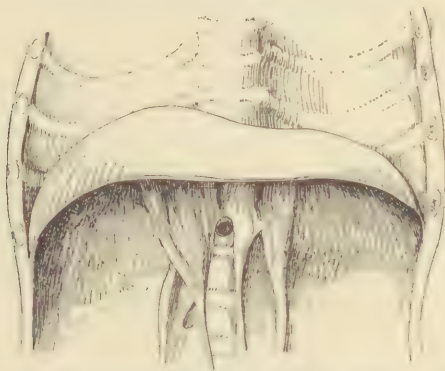


FIG. 71.—The diaphragm between empty body cavities. The ventral border has been cut away to some extent. (See text.)

tachments upward toward a stationary center. If the ribs could move freely in any direction this would narrow the lower part of the chest. But since, in reality, they cannot rise without spreading, the movement is still inspiratory. In such circumstances the diaphragm has merely taken its place among the other muscles which are adapted to elevate the ribs. If one inspires as deeply as possible it will probably be noticed that up to a certain point the abdominal wall is pushed steadily out; before the movement is carried to its limit the wall has begun to fall back. The protrusion indicates that the diaphragm is bearing down upon the viscera; the reversal

comes when the rising of the ribs more than compensates for this.

Expiration.—Inspiration requires a marked exertion. Expiration is promoted by certain factors other than muscular contraction. Mention may be made of: (1) the elastic tension of the lung tissue, lately referred to; (2) the elastic reaction of the abdominal wall tending, through the medium of the viscera, to thrust up the diaphragm; (3) the elastic reaction of the cartilages uniting the ribs with the breast bone, and (4) gravity, for when we breathe in we have usually to raise a weight. Muscles are employed to a variable extent to compress the abdomen and draw down the ribs. The muscular activity may be strenuous when expiration has a forced character, as in shouting or blowing forcibly.

The Closed Glottis.—The glottis is the cleft between the vocal cords in the larynx through which the breath must pass. It is the narrowest segment of the respiratory path. It can be very securely closed by the muscles which flank it. When the glottis is closed the air in the lungs becomes a substantial cushion. We instinctively confine it when we make any great effort and the upper part of the body is thereby firmly supported. It is like screwing up the valve without which the automobile tire has no power to bear weight. An expiratory effort with closed glottis throws pressure by means of the air cushion directly upon the heart, hindering its diastole, and upon the veins, which may be much compressed. The reddening of the face is a sign of the backing up of the blood along the veins, and the interference with the circulation may be great enough to cause dizziness.

The Tidal Air.—When one is breathing quietly the volume of the air which enters or leaves the nostrils at a single breath is said to be about 30 cubic inches. This quantity is called the tidal air because of its regular coming and going. At each breath some air is carried from the sacs of the lungs to the exterior and replaced

with fresh air. But we cannot say that the whole volume of the tidal air is thus removed and replaced. We have to make allowance for what is called the *dead space*.

This term is applied to the volume of air contained in the nasal passages, the pharynx, the trachea, the bronchi, and the branching bronchial tubes which lead to the microscopic sacs. It amounts to about 10 cubic inches. We are somewhat handicapped by the existence of the dead space, as will now be shown. Suppose that an expiration is just completed. The passages constituting the dead space contain air arrested on its way out from the depths of the lungs. Inspiration begins. All the vitiated air in the dead space must be borne back again into the terminal sacs before any fresh, atmospheric air can enter them.

Again, at the height of inspiration the dead space is occupied by fresh air. During expiration all this good air must be rejected before the impoverished air from the actual seat of the respiratory exchanges begins to escape from the nostrils. It is easy to see that a man breathing through a long rubber tube would be suffocated, because he would merely move back and forth the same air instead of obtaining fresh supplies. We are unavoidably hindered by the actual dead space, according to the same principle, but the impediment is not a serious one. It will appear that the deeper the breathing the smaller the fraction of the total represented by the dead space. On the other hand, when the breathing becomes shoal from any cause the fraction corresponding to the dead space becomes progressively larger. If the tidal air sinks to 10 cubic inches there is little or no useful surplus over the alternating movement within the passages.

The Vital Capacity.—It is evident that we seldom breathe as much as we can. The ordinary tidal air is perhaps only one-eighth of the total volume which we can take in after a forced expiration or expire after the

deepest inspiration. The maximum volume of a single breath, commonly about 250 cubic inches, is called the vital capacity. It is often spoken of as the capacity of the thorax, but this is evidently inaccurate. After the most intense expiratory effort there is still air in the lungs which we cannot crowd out. This is the so-called *residual air* and it is said to amount to some 60 cubic inches. It is our habit to breathe with the chest in an intermediate position, about half way between extreme distention and severest compression.

The Changes in the Respired Air.—These are partly physical and partly chemical. In the former class we note the warming and saturation of the air already mentioned. As much as a pint of water may be removed from the body by the breath in the course of twenty-four hours. We ought not to say that this is from the lungs for it comes chiefly from the nasal lining. The air is warmed and moistened on its way in and the water from the nose is carried into the lungs to be brought back again to the exterior.

The chemical changes call for a fuller statement. We anticipate that expired air will contain less oxygen than standard atmospheric air and more carbon dioxid. The actual alteration is less extensive than might be expected. The outside air contains nearly 21 per cent. of oxygen; the percentage in expired air may be reduced to 16. The quantity of carbon dioxid in the atmosphere is insignificant—about 0.04 per cent. The amount in expired air may be 4 per cent. or a little more. All such figures are naturally subject to variation. But we have learned to anticipate that a disappearance of 5 volumes of oxygen will be simultaneous with the discharge of 4 or 4.5 volumes of carbon dioxid.

The fact that the carbon dioxid discharged is normally a little less than the oxygen consumed has an interesting significance. If all the oxygen taken into the blood-stream went to form carbon dioxid the volume of this gas would just equal that of the oxygen used to generate

it. But a moderate amount of water is constantly formed as a second respiratory product. The oxygen which goes to form water, of course, fails to appear in combination with carbon. Later on we shall find that the proportion between the oxygen absorbed and the carbon dioxid evolved by an animal furnishes valuable information to the student of metabolism.

If the expired air contains 16 per cent. of oxygen and 4 per cent. of carbon dioxid, as we have assumed, we must still bear in mind that the first portion of each expiration is from the dead space and hence almost like fresh air. It follows that the *last* part of each expiration is lower in oxygen and higher in carbon dioxid than the average of the whole and that it is a fair sample of the air in the terminal sacs of the lungs. Such air may contain nearly 6 per cent. of carbon dioxid and something like 14 per cent. of oxygen. It is the *alveolar air* and it is this which we must consider as standing in relation to the blood in the pulmonary capillaries.

The nitrogen which makes 79 per cent. of the atmospheric air is not believed to be drawn upon or added to by the blood. This is the case, at any rate, in the long run. When there is a rise of barometric pressure there is doubtless some absorption of additional nitrogen by the blood and when the pressure falls again there is some yielding up of nitrogen. But this is an accidental matter and not related to the life-processes.

Whether anything of an organic nature passes out with the expired air is a question that has been much discussed and perhaps not fully decided. It used to be asserted that the breath carries from the body compounds of a volatile and poisonous character. This has been difficult to establish by experiment. Of course the breath may have an odor and this indicates the presence of some substance but not in quantity to be measured by other tests than the olfactory. Odor, when present, is not likely to be due to anything coming from the lungs

but to remains of food, decaying teeth, and degenerating tissue about the tonsils and pharynx.

Ideals of Ventilation.—This is a subject which may be touched upon here. We all recognize that rooms in which the air is not freely changed become “stuffy” and depressing to work in. Just what constitutes “bad air” as noticed in such situations has been differently interpreted by writers of different periods. The simple idea that air in close rooms lacks oxygen or is overcharged with carbon dioxid cannot be maintained. The existence in it of volatile poisons is, as we have said, hard to establish. An odor may have a considerable effect upon the human nervous system and it is to be noted that odors in ill-ventilated places are not due simply to the breath but proceed from skins, clothing, lights, and many other sources.

According to the opinion now generally held the chief trouble with an atmosphere that is regarded as stuffy or close is that it is overheating to the skin. The surface of the human body is kept comfortably cool under favorable conditions by the air currents which pass over it and by the evaporation of perspiration. The former are an aid to the latter. In a confined space there is a lack of movement in the air and it tends also to become warm and humid. Moisture is not taken promptly from the skin and its temperature rises. A vasomotor reflex is encouraged by which the cutaneous vessels are dilated and, with the increased blood-flow, the unpleasant warmth is made more pronounced. There is likely to be some reduction of the general blood-pressure, leading to drowsiness or, at least, a feeling of inertia.

If these views are correct, the most effective precautions that can be taken to secure comfort in a room are to keep it cool and to have some circulation of the air. Our fear of strong drafts may be a wholesome one but we should also avoid stagnation. It has been shown that starting an electric fan in a close room may relieve an almost intolerable condition. It does not improve

the air chemically but it favors the removal of heat from the bodies of the inmates and braces up their vasomotor systems. An English writer, adopting a novel but suggestive point of view, has said the real difficulty with a stuffy room is that there is a lack of stimulation for the nervous system. One becomes relaxed and indolent because the receptors are not being played upon as they would be by a breeze or even by a decidedly chilling air. This is consistent with the recognized fact that the most comfortable climates do not make for the greatest efficiency.

We may ask in passing what are the causes of death when people are huddled in narrow quarters. The classic illustration is that of the Black Hole of Calcutta. About 150 English soldiers were confined through a tropic night in a room 20 feet square. There were but two windows, both on the same side of the room. Only twenty-three men survived. Perhaps in a case as extreme as this actual shortage of oxygen and damaging excess of carbon dioxid might have been realized. There might also have been definite poisoning from volatile excretions. But another factor which we cannot overlook must have been the collective rise of temperature resulting from the crowding together of so many bodies. This was made more acute by the struggle which went on among the agonized prisoners.

CHAPTER XXI

RESPIRATION (Continued)

Once or twice each minute all the blood in the body passes through the capillaries of the lungs. As it enters from the right side of the heart it is reckoned venous; it goes on to the left auricle and ventricle arterial blood. It has been stated before that arterial blood contains about all the oxygen which can be attached to the hemoglobin of the corpuscles, while average venous blood is not by any means devoid of oxygen. It is likely to retain upward of half the amount of the gas originally present. The facts concerning the carbon dioxid are perhaps rather unexpected.

Carbon dioxid is the most abundant gas even in arterial blood. So much of it is constantly present there that the increase in venous blood seems rather slight. The quantity obtainable from 100 volumes of arterial blood may be in the vicinity of 38 volumes. From 100 volumes of venous blood about 45 volumes of carbon dioxid may probably be removed. (Blood exposed to a vacuum will froth and rapidly give off all the mixed gases which it has been holding.) The oxygen in 100 volumes of arterial blood may be 20 volumes; in venous blood about 12. These figures are not to be accepted as rigid and unvarying. Other quantities are quite as likely to be reported, but the order of magnitude will not be entirely different.

The time during which any single corpuscle or any portion of plasma is in a position for respiratory exchange is only a second or two. It is shorter when the circulation is accelerated to support muscular activity. Yet it appears to suffice for the purpose. There is some uncertainty at the present time whether the delicate cells through which the transfer of oxygen and carbon dioxid must take place act like an inert membrane or apply energy of their own evolution to promote the

process. The common teaching has been that they are indifferent to what is going on as if they were lifeless structures but we may be obliged to credit them with a definite participation in the performance.

Internal Respiration.—Emphasis has been placed on the preliminary character of the exchanges occurring in the lungs. It has been insisted that respiration in the best sense of the term is a function of the tissues at large in proportion as they share in the general metabolism. We sometimes distinguish this genuine biologic respiration as *internal*, contrasting it with the pulmonary give and take which we call external respiration. From this point of view external respiration makes venous blood arterial and internal respiration makes arterial blood venous.

While the blood is flowing slowly through the systemic capillaries, it is separated from the surrounding lymph by a partition of the most delicate description. The living cells, contractile or glandular or other, are in contact with the lymph. They keep the oxygen content of the lymph at a low level but do not absolutely exhaust it because its very poverty in this gas is an invitation to bring in fresh supplies from the passing blood. The immediate source is the plasma but this has a very limited oxygen capacity and when drawn upon it takes more from the corpuscles, turning oxyhemoglobin into reduced hemoglobin.

Meanwhile the active cells are thrusting the carbon dioxid which they produce into the lymph and raising the concentration of the waste in this fluid to a point favorable to its transfer into the blood. It enters the plasma and is carried mainly by that part of the blood in various obscure combinations. A moderate share is united with the hemoglobin of the corpuscles which can contain carbon dioxid without losing their power to hold oxygen.

Carbon Monoxid.—This is a gas (CO) which is not to be confused with carbon dioxid (CO_2). It is formed when carbon is burned with an insufficient supply of oxygen gas,

as when fresh coal is placed upon the top of a furnace fire. It does not arise in the living body and its interest in this connection comes from the danger of inhaling it. We may be subjected to its effects when it has reached us from fires or when illuminating gas escapes into our rooms. The common form known as "water gas" contains it in great quantity. It is very poisonous and for a simple reason: it deprives the blood of its oxygen-carrying capacity.

Carbon monoxid does this by substituting itself for oxygen in the oxyhemoglobin molecule. The unnatural compound formed circulates with little tendency to release the carbon monoxid which is locked in it. (Fortunately, however, it is not absolutely stable. When fresh air has replaced that which brought the foreign gas into the lungs, the movement of the carbon monoxid molecules is reversed; they now begin to leave the blood.) Just so far as the corpuscles are engaged in carrying this useless gas they are incapacitated for their essential service. If the substitution becomes extensive enough the lack of oxygen is fatal, the heart and the nervous system failing for want of it much as though the victim were bleeding to death. The blood, when saturated with carbon monoxid, has a light color described as cherry red and does not darken on standing as normal blood does.

Breathing Pure Oxygen.—The impression is common that the experience of breathing pure oxygen is a highly exhilarating one. This is not really the case unless an element of suggestion secures the anticipated result. If a man does not know that he has been given the oxygen to breathe he is not likely to report that the experience is at all peculiar. Nevertheless oxygen has often seemed to be of the utmost value in critical pulmonary disease. We must try to reconcile the negative reaction of one who breathes it in health and the marked relief of the pneumonia patient. A simple statement may explain the difference: oxygen does not alter the composition of normal blood in a way that will much affect the organism but it is potent to restore to the standard blood which may have fallen below in illness.

It has lately been shown that oxygen is distinctly helpful to athletes in certain trials of strength and speed. This is best evidenced by middle-distance runners. They do not greatly improve their time under its influence but they finish with a minimum of distress. How can we find any condition common to the runner in the height of condition and the sick man fighting for his life? This is easier than might be supposed. Both are tending to suffer from a falling of the blood below its normal composition as regards oxygen. In the case of the athlete this is due to the great demands which his muscles are making upon the blood. In the case of the sick man it is not huge consumption of oxygen but restricted supply which is responsible for a somewhat similar chemical disturbance.

The healthy, resting man, if he breathes oxygen, adds something to the amount circulating in his system. But his tissues were already having offered to them so liberal a supply that they returned much unused in the venous blood. No important results will follow if they are offered more. The tissues will not burn under "forced draft." This is an important difference between the relation of oxygen to living things and to fires.

Compressed Air.—In many engineering operations, especially in constructing tunnels or laying foundations far below water, it is necessary to fill the spaces in which the men are working with highly compressed air. The atmospheric pressure is about 15 pounds to the square inch. At 34 feet below water twice this pressure must be provided to keep the water pressure balanced. At 68 feet the air pressure must be three times the atmospheric, three atmospheres, as we express it. Such works have often been carried on at greater depths than this and pressures of four or more atmospheres have been employed. Divers can descend for short periods to levels at which the air pumped into their helmets has to be compressed to six or seven times the normal density.

It has long been known that compressed air has its dangers. Only slight disturbances are experienced on being introduced into it, but serious or even fatal effects may follow emergence from it. The symptoms range all the way from dizziness and muscular pain to apoplectic death. Experience has shown that the workmen must spend some time in atmospheres of intermediate pressures when coming out of deep workings. Technically speaking, they must be decompressed by stages. The various troubles manifested in cases of too rapid decompression are spoken of collectively as caisson-sickness, divers' palsy, or compressed-air illness.

The earlier theories advanced to account for these difficulties were elaborate and confusing. The actual basis of caisson-sickness has been found to be exceedingly simple. What happens in the tissues of a man who comes too hastily into the open after a stay in compressed air is just what happens when a bottle of charged water is uncorked; there is a formation of bubbles, an effervescence. During the previous period both oxygen and nitrogen have been absorbed in unusual amounts, first by the blood and secondarily by the tissues. It is the nitrogen in this case which threatens damage by separating itself in the form of minute bubbles when the pressure that held it in solution is removed. One can understand how the most varied effects may follow the development of bubbles in one place or another.

Nitrogen bubbles forming in the nervous system may so disorganize its structure as to work a mortal injury, perhaps by playing havoc with the respiratory center. Their presence in muscles and joints may result in nothing more serious than pain and stiffness. The conditions will be slow to pass off for the cells of the body have little affinity for nitrogen and, in fact, it is hard to account for its final disappearance. A certain rigidity of the joints is so often experienced that it has given to caisson-sickness the colloquial name of "the bends" commonly applied to it by workmen.

Carbon Dioxid and the Respiratory Center.—A brief statement was made in Chapter VIII respecting the control exercised by the medulla over the breathing movements. Attention was there drawn to the fact that the center from which the impulses issue to command the respiratory muscles is regulated in its action largely by the concentration of carbon dioxid in the circulating blood. The changes in the quantity of this gas are very positive sources of influence upon the neurons of the center. To make this clear it will be well, first of all, to show that the composition of the air in the lungs has little if any effect on the character of the breathing. The center is responsive to the chemical state of its immediate environment rather than to that which prevails in the air-sacs. A striking experiment shows this decisively.

Two rabbits are anesthetized and placed side by side. By an operation of some delicacy connections are made which lead the blood from the arterial system of rabbit A to the head of rabbit B. Similarly the arteries of rabbit B are made to supply the head of rabbit A. If the trachea of rabbit A is now obstructed it is the second animal which shows the labored breathing movements of asphyxia. The air in the lungs of rabbit A is falling off in oxygen and gaining in carbon dioxid but this does not stimulate the nervous mechanisms so long as the standard blood of rabbit B is flowing through the vessels of the brain.

When the composition of the blood tends to be altered either because of restricted breathing or excessive muscular activity we may expect a simultaneous rise in the carbon dioxid of the blood and a fall in its oxygen. How do we know which of these changes stirs the respiratory center to compensatory action? It is possible for purposes of experiment to separate the two. A trial may be made upon the human subject without undue hardship. A man may breathe in and out of a silk bag, his breath passing back and forth through a

vessel containing alkali. Exposure of the air to the alkali will remove the carbon dioxid, but there is no provision here for a restoration of the consumed oxygen.

The subject of such an experiment as this will breathe for a long time without any exaggerated efforts and without feeling distressed. He may become quite blue and will perhaps lose consciousness if the trial is not interrupted. It appears that lack of oxygen does not strongly excite the respiratory center even when it is threatening to prove fatal. The complementary experiment consists in giving a man a mixture of carbon dioxid and oxygen to breathe. In this case labored breathing will result, even though the mixture be 95 per cent. of oxygen to 5 per cent. of carbon dioxid. The blood is perfectly arterialized so far as oxygen is concerned but a very moderate increase in its carbon dioxid, due to the difficulty of shaking off the waste under such circumstances, is enough to act powerfully on the center.

Forced Breathing.—If a person sets himself at work to breathe as fast and deeply as he can he will soon be uncomfortable. He may be dizzy or faint. The inclination to stop forcing the breathing becomes hard to resist. In fact it is almost as hard to overbreathe as to underbreathe, if these expressions may be allowed. The effects of breathing a greater volume of air than that needed to meet current needs are attributed to a reduction of the carbon dioxid in the blood. The condition in which the carbon dioxid of the arterial blood is below the standard is known as *acapnia*.

In view of the fact that carbon dioxid is the foremost of animal waste-products it might be supposed that it could not be too thoroughly removed for the advantage of the organism. But our natural impression has proved to be wrong. When the lungs are rapidly ventilated the alveolar air comes to have an unusual composition. It approximates to the fresh outside air. The increase in oxygen, perhaps from 14 to 18 per cent., has little effect on the blood. The simultaneous decrease in the alveolar

carbon dioxid from something like 6 per cent. to half as much permits a reduction in the carbon dioxid of the blood which has marked results.

It seems to be established that a certain concentration of carbon dioxid in the blood and tissues is necessary to normal reaction. We may think of the gas as having a mild stimulating effect upon the nerve centers and assume that the want of it results in a paralysis of some of these cell-groups. The case of the respiratory center seems especially clear. We have seen that this center is stimulated to increased activity when the local concentration of carbon dioxid is raised. Conversely it may cease to act for a time if the carbon dioxid in its vicinity is cut down. Thus *acapnia* produces a suspension of breathing—*apnea*, as we call it. When the breathing is at a standstill an increase of carbon dioxid is to be expected and this will lead to a resumption of breathing within a short time. Yet it is possible that the stimulus to resume breathing may not be furnished until the shortage of oxygen has wrought irreparable damage.

High Altitudes.—The barometric pressure is lowered progressively as one ascends from the sea-level. At a height of 15,000 feet, corresponding to that of the Alps and the Rockies, it is reduced to about one-half the coast standard. This reduction may be thought of as affecting both the nitrogen and the oxygen gases. (The share of the total pressure which can be referred to any gas in a mixture is said to be the "partial pressure" of that gas.) No distinct results follow the gradual diminution of the partial pressure of the nitrogen as one goes up a mountain but the lessening of the oxygen pressure makes itself felt.

If the oxygen in the blood were taken up according to the laws of physical solution, halving the pressure would also halve the quantity of the gas absorbed. But we have seen that the union of oxygen with hemoglobin is a chemical one and it is rapidly accomplished even

when the pressure of the oxygen is far less than usual. Nevertheless a sufficiently radical reduction of the oxygen pressure tends to lessen the amount received by the blood and the want begins to be felt in the nervous system. Deficiency of oxygen supply to active tissues has one outstanding result: it leads to an accumulation of acid, to *acidosis* as we say.

The acid which begins to gather when the oxygen supply is short is chiefly lactic. We have already mentioned this among the fatigue substances arising in working muscle. It can be rapidly and completely removed if oxygen is freely obtainable. If its formation continues it acts as a poison. *Mountain sickness*, the combination of ill effects experienced by those who go to high altitudes for the first time, is believed to be due mostly to lactic acid formation. As observed on Pike's Peak in subjects who are not exerting themselves it is said to begin with a period of nervous irritability. This is succeeded by nausea and vertigo and these symptoms in their turn by persistent and severe headache. The sequence is like that exhibited in connection with alcoholic indulgence.

While these manifestations are best explained as signs of acidosis it has been suggested by writers dealing with this subject that a certain degree of acapnia is to be expected. In a rarefied atmosphere the breathing must be deepened to keep an adequate oxygen pressure in the alveolar air. There is no difficulty, however, in working off the carbon dioxid which leaves the blood quite as freely as at the sea-level. An awkward dilemma arises: the breathing must be forced to secure enough oxygen, yet it cannot be forced without establishing some measure of acapnia.

Acclimatization.—It would be interesting to know all the changes which take place in the human system when it is becoming adapted to life at an altitude previously unwonted. One of the earliest to be recognized was a marked increase in the number of the red corpuscles.

If the charge of oxygen borne by a single corpuscle is smaller at the new habitation than it was at the old there will clearly be a gain in adding to the number of the carriers. But we shall probably be wrong if we make the increase in the number of corpuscles the principal feature of the adaptation.

Students commonly fail to appreciate that the maintenance of respiration calls for an efficient and economically directed circulation just as urgently as for sound lungs and trained breathing muscles. A person will be breathless if his circulation is not equal to its task, regardless of his success in ventilating the lungs. When exercise is undertaken there must be a coördination between the increase of the breathing and the acceleration of the blood-flow. It is hard to see that anything is gained by the first unless it is supported by the second. In becoming acclimated to life at a high altitude one may be supposed to acquire several advantages. The breathing muscles become stronger and their energy is better directed. The heart is trained. The vaso-motor adjustments give the best possible direction to the blood-stream. There are more corpuscles available as noted above.

Some investigators hold that after giving due weight to all these possibilities it is still necessary to add another to the list. This remarkable adaptation, they claim, is a local change in the nature of the cells lining the air-sacs of the lungs. It is asserted that there is evidence to show that these epithelial cells gain a power which they did not have before, the ability to promote the transfer of oxygen from the air to the blood by some application of their own energy. It is hard to tell whether this view will be widely accepted. It is a sound principle to make the most of the simpler explanations that offer themselves before resorting to those that are more complicated. We may find, however, that an active intervention on the part of these cells must sometimes be assumed.

The Hygiene of Breathing.—A great deal is written by popular teachers of hygiene in support of habitual deep breathing and the practice of special breathing exercises. It is certainly desirable to be able to breathe deeply, to have a large vital capacity. It is not well to fall into indolent habits which lead to the disuse of many of the muscles adapted to help in inspiration nor to fail to use all parts of the lungs at times. The resistance of the lung tissue to tuberculosis and other diseases is undoubtedly increased when it is well subjected to mechanical movements.

On the other hand, contrary to the usual instruction, the best breathing exercises are those which are taken involuntarily as a part of general muscular activity. We have seen that it is possible to derange the composition of the blood by overbreathing. We cannot easily overbreathe when a great respiratory requirement has to be met, as in running or playing tennis. We may breathe deeply without tending to produce acapnia if we slow the rhythm of the movements at the same time. Singing is an excellent exercise, demanding as it does the quick, strong intake of the breath and the prolonged, carefully regulated expiration.

It has often been noted that breathing exercises have well-marked mental effects. Too much has probably been made of this fact and undesirable results have often been spoken of as though they were to be sought for. Acapnia produces mental confusion and the state has been described as one of exaltation. Oriental religionists have urged this claim upon their western disciples. From a scientific standpoint it appears morbid and dangerous. The mild emotional reaction of the singer is as much as can safely be recommended.

While there is no good reason to advise people to breathe more deeply than their inclination suggests, it is desirable to breathe from a high base-level—that is, with the chest well rounded even in expiration. This habit, if not foolishly exaggerated, helps to maintain

good posture, to give the heart a clear space in which to work and a desirable traction outward to assist its diastole. It also widens the cross-section of the pulmonary vessels so that the blood need not be hurried through them, lengthens its time of exposure to the alveolar air, and lightens the labor of the right ventricle. There are various involved relations of a mechanical sort between the breathing movements and the blood-flow which are too difficult to discuss in a work like the present.

CHAPTER XXII

METABOLISM

The word metabolism has been used once or twice before this time to signify the sum of the chemical changes taking place in the body. The German equivalent is very significant: it is the word *Stoffwechsel*, which means "transformation of matter." We exclude from the subject the digestive reactions which go on in the alimentary tract; strictly speaking these do not occur in the body but near its surface where it is infolded. Our starting point must be the absorption of the digestive products, the final topic of Chapter XV. Most of what we have now to discuss might be entitled *The History of the Food after Absorption*.

Metabolism of Fat.—The story is most simple in the case of the fats. It will be recollected that these compounds are decomposed in the intestine but reconstructed, it appears, in the very act of passing through the epithelial wall. Drops of fat occur in the lymph of the mesentery and give it the milky character which long ago fixed the name of lacteals upon these vessels. It is known that most of the fat entering the circulation after a meal traverses the thoracic duct. This was ascertained by observing cases in which the duct had been severed so that the lymph stream escaped through a wound. After a meal containing a known amount of fat about two-thirds of it could be recovered in the collected lymph.

The fat which is generated in the intestinal wall from the cleavage-products of fat previously fed and digested is not a mere reproduction of the original fat. It has a constant composition proper to the species and independent of variations in the nature of the fat furnished

in the diet. So an animal eating a vegetable oil does not store the same oil in its adipose tissue, but accumulates there a fat which conforms to its own standard. The only exception is noted when a fast is followed by abundant feeding; at such a time there may be some retention, for a while, of a distinctly foreign fat.

Most of the fat in the body is in what we have called adipose tissue. When we spoke of peptic digestion we described this as a tissue rich in fat but not composed solely of that material. It is a form of connective tissue with fibers between the cells. But while, as a rule, the intercellular substance makes up the bulk of any con-



FIG. 72.—Cells in adipose tissue distended with fat. Note the capillary, fibers, and undeveloped cells.

nective tissue we recognize an exception in this case. The fat carried is *intracellular*, that is to say, enclosed in the cells instead of being placed between them. It is so abundant that the cells have a swollen appearance, their nuclei are pushed to the surface, and their true protoplasm is a mere envelope for the fat drops within.

Adipose tissue is found even in lean animals to an amount not usually suspected. A considerable mass is normally present below the diaphragm and about the kidneys. The white marrow in the hollow shafts of the long bones is essentially adipose tissue. When the

pioneers in crossing the deserts of Nevada killed their famished oxen for food they were disappointed to find this marrow replaced by fluid; the animals had nearly exhausted this reserve along with other deposits. Some adipose tissue is usually found about the heart, behind the eyes, and in the mesentery.

In well-fattened individuals these accumulations are supplemented by others. Chief of these is the *subcutaneous fat*, a layer between the skin and the muscles. This may be indefinitely increased and its prominence determines our judgment as to whether a subject is obese or not. Corpulent persons have much adipose tissue in the great omentum, making this appendage to the stomach a massive affair instead of the filmy apron which it is ordinarily. We may assume that the average human adult has at least 4 or 5 pounds of fat in his system.

The ultimate service of this fat is to be oxidized and to contribute its energy to the working tissues, particularly the skeletal muscles. To perform this function it must first be carried from the seat of its temporary storage to the contractile organs. This transfer occurs most actively in periods of fasting when the organism is feeding upon its own stores. The blood of a starving animal may be richer in fat than is usual during mixed feeding for it is engaged in this work of transportation.

When fat is fully oxidized the only end-products are carbon dioxid and water. In certain pathologic conditions, notably in severe diabetes, the oxidation of fat is incomplete and certain less simple compounds are formed. These are of an acid character and their accumulation in the blood and elsewhere may be responsible for a profound poisoning. This is appropriately called an *acidosis*. Very much as when we fail to burn coal cleanly and completely we get the poisonous carbon monoxid, so when fat is not effectually oxidized in the body we have generated products which are immeasurably more injurious than the normal ones.

Carbohydrate Metabolism.—We have seen that in the course of digestion starches and complex sugars are changed to sugars of the simplest order. By far the most abundant of these simple sugars is the one which we call *dextrose*. It is identical with the sugar found in grapes. Our account of carbohydrates in the body resolves itself into a history of the use made of dextrose by the tissues. Within a few hours after a meal 4 or 5 ounces of this sugar may enter the portal circulation. This sugar will be offered to the liver cells before it is presented to any other organ. The clue is an important one and was long ago followed by Bernard with fruitful results.

The liver of a well-nourished animal contains carbohydrate to an extent that other organs do not approach. The particular representative of the carbohydrate class is more like a starch than a sugar; it is of high molecular weight and limited solubility. It is found within the cells of the liver in small solid clumps. We sometimes call it animal starch but more often *glycogen*. The word means "sugar former" and the reference is to the readiness with which glycogen undergoes digestion and is resolved into dextrose. The human liver may contain as much as 6 ounces of glycogen; in herbivorous animals, such as the rabbit, the proportion may be higher than in man.

Since we know that the liver stands in the path of the incoming carbohydrate, and since we find this organ rich in a starch-like substance, it is natural to infer that some portion of the absorbed sugar may be arrested and retained by the liver. It is turned into glycogen by a change which is a condensation, the reverse of digestion. It remains subject to reconversion to dextrose, in which form it is dealt out to the blood in times of fasting. There is a definite resemblance between the liver, so far as this function is concerned, and a tuber like a potato. The liver and the potato are both repositories of surplus carbohydrate and in both cases the material enters and

leaves in the form of sugar. It is held in storage in the less soluble and more manageable forms of glycogen and starch respectively. While glycogen is conspicuous in the liver it is formed and retained by other tissues to some extent. The skeletal muscles, in particular, contain it in a small percentage but a large total quantity. They constitute a mass of tissue many times larger than the liver and they are supposed to contain rather more glycogen than the great gland where it was first found.

Owing to the tendency of the liver and the muscles to make glycogen when an excess of sugar is brought under their influence and to return sugar to the circulation when there is no influx from the intestine the blood is protected against alternate surcharging and impoverishment. Its sugar content does not rise materially unless a great deal of sugar is fed. It is sometimes possible, however, to exceed the capacity of the tissues for storing glycogen and to establish for a short time a condition of *hyperglycemia*, an abnormally high percentage of sugar in the blood. If this is at all marked some sugar will pass into the urine; the kidneys will abstract it from the blood if the liver and muscles fail to do so. The appearance of sugar in the urine in consequence of eating largely of it is called *alimentary glycosuria*.

If the carbohydrate supply of the body is for some time in excess of the current consumption the formation of glycogen will not be indefinitely continued. Instead, there is likely to be a transformation of some of the starch and sugar consumed into body fat. The maximum storage of glycogen is probably about 1 pound. When this limit is approached conditions are favorable for the development of more or less fat from carbohydrate. This possibility was once denied but has been proved by careful experiments as well as by practical experience. We have every reason to believe that starches and sugars are responsible for much of the corpulence which is such a common and serious condition.

It was once held that body fat could come only from fat received in the food. This view was absolutely disproved by a single argument on the part of the great chemist Liebig. He called attention to the scant supply of fat in the fodder of the cow as compared with the large daily delivery of butter fat in the milk. No one could maintain the old belief in the presence of these facts. But Liebig merely showed that fat could come from something other than itself, and it was not at once decided whether proteins or carbohydrates were to be regarded as the usual source. It may be said in anticipation of what is to come later that proteins are possible fat-formers, but not generally so prominent as the carbohydrates.

The transformation of sugar to fat being a well-established and frequent occurrence, it becomes natural to inquire whether fat can be changed back again to sugar. This seems easier from a chemical point of view than the former reaction. But it has proved difficult to demonstrate that it ever happens. There is at present a difference of opinion in regard to it and it may well be considered an open question.

As was said of fat so it may be said of carbohydrate that its essential service is performed when it is oxidized with liberation of energy. There is a further correspondence between the two in that the oxidation is mainly effected in the skeletal muscles and that the normal end-products are carbon dioxide and water.

The Pancreas.—The oxidation of dextrose stands in a curious relationship to the normal activity of the pancreas. We have dealt with that organ as a digestive gland of great importance. We are now to see that it has another function even more fundamental. About the year 1889 certain investigators removed the pancreas from dogs to observe the signs of deficiency which might make their appearance. It would have been natural to look for some loss of digestive capacity and a lowered power to absorb food. Probably these results ensued

but they were obscured by a much more striking consequence: the loss of the ability to oxidize sugar.

We must bear in mind that the oxidation of sugar does not take place *in* the pancreas and yet the influence of that gland is one of its necessary conditions. It has to be assumed that some agent derived from the pancreatic cells enters the circulation and travels to the tissues far and wide, conferring on them the power to set free and utilize the energy that is latent in the sugar molecules. The agent concerned is a hormone as defined in Chapter XV. It is not precisely an enzyme but reminds us of that type of substance in that it is known by its effects rather than as an isolated body.

Lack of the pancreatic hormone—with consequent lack of the capacity to make use of dextrose—is the central condition in the disease *diabetes*. This is popularly supposed to be a “kidney trouble” but it is not. When the body cannot oxidize sugar the continued addition of this digestive product to the blood leads to hyperglycemia. An escape of sugar in the urine is then to be expected, for normal kidneys always let it pass when the concentration on the blood exceeds a certain low limit. Unlike alimentary glycosuria, the diabetic state means an abundant and more or less continuous loss of sugar. In fully developed cases all the sugar entering the blood is transferred to the urine without having contributed to the activities of the tissues.

It might be anticipated that in diabetes the glycogen of the liver and muscles would be maximal in amount. On the contrary the power to make and hold this derivative of sugar seems to be lost along with the ability to oxidize. The pancreatic hormone appears to confer both the power to oxidize sugar and the power to convert it into glycogen. When diabetes reaches its full intensity and no dextrose can be broken down there follows, as already noted, a faulty fat metabolism and acidosis of the gravest kind.

Alcohol.—Alcohol when taken is absorbed rapidly and rather quickly oxidized. It yields up heat and gives rise to carbon dioxid and water. It is not known to be transformed into fat or glycogen so there is no apparent provision for its storage. The familiar fattening effect of alcoholic drinks is indirect. It can be referred to two circumstances: in the first place moderate drinking creates a keen appetite and so favors overeating; second, when alcohol is oxidized in the body there is less call for the oxidation of fat or carbohydrate to meet the current need. Fat is thus “spared” to accumulate, or carbohydrate to be transformed into it.

Nitrogenous Metabolism.—An equivalent for this title would be *The History of the Amino-acids*. No one can pursue this subject far without the fullest command of the facts of biochemistry. Our treatment must be condensed and admittedly superficial. We have said that the amino-acids are the structural units, the “building stones,” of protein. What we call a single protein, for instance, the albumin of white of egg, yields a considerable number of amino-acids when it is thoroughly digested. The total number known is about twenty.

These diverse substances pass from the intestine into the portal blood-stream. It was once held that they were immediately combined to form proteins of the types native in the plasma. This is no longer believed; while there must be some synthesis of new proteins from the amino-acids it seems to be quite limited. Of course it must be greater during the period of growth than it is in a body which is no longer increasing in size. It never ceases entirely for the proteins of the muscles and glands are subject to a gradual disintegration so long as life lasts and the losses need to be made good.

According to one conception the proteins of the plasma are offered to the tissues and appropriated by them as may be required. To turn the proteins of the blood into those of muscles it has been supposed that a local digestion is carried on and the amino-acids combined accord-

ing to a new pattern. A more recent view is somewhat simpler. This is to the effect that it is the free amino-acids rather than the proteins of the plasma on which the various tissues depend for their renewal. We are left somewhat in doubt as to the real value of the blood proteins.

During starvation it is known that some organs are sustained while others are suffered to waste. Thus the heart and the brain are preserved almost intact while the spleen and the liver lose largely in weight. At such times we may picture the proteins of the less essential organs becoming resolved into amino-acids which can be incorporated into those which must be protected. A striking case is that of the female salmon when the time for spawning is approaching. The muscles steadily atrophy and there is no doubt that their substance is made to contribute to the growing mass of roe.

It used to be held that one protein must be equivalent to another. The impression was a natural one so long as attention was directed only to the percentage composition of proteins from different sources. Their content of oxygen, nitrogen, carbon, etc., varies but little. When the significance of the "building stones" came to be appreciated it became clear that certain proteins may be much more serviceable than others for the general work of nutrition. If they do not furnish all the constructive units called for they may be hopelessly inadequate. One example of an inadequate or defective protein has long been known. This is *gelatin* from the connective tissue of meat and from bone.

Gelatin was found long ago to analyze like protein in general. It seemed to carry the standard quantity of nitrogen and the other elements. Yet it never could replace other proteins in the diet of animals or men without initiating a decline of weight and condition that would continue to the end of the trial. We have learned now that the difficulty with gelatin is the absence of one or two amino-acids from the list of its cleavage-

products. It fails to furnish certain "building stones" which are indispensable. There are a number of vegetable proteins which resemble gelatin in their failure to supply important amino-acids. Their existence was not evident until special studies demonstrated it, because they were found in close association with other proteins of a superior sort from which they had to be separated before they could be tested as individuals.

As there are proteins which cannot satisfy all the requirements of animal life, so there are others which can do so, but only when consumed in what seems an extravagant manner. The trouble with these proteins is that while they give all the needful amino-acids, they yield them in proportions not corresponding to the demand. If the body needs a good deal of an amino-acid which a certain protein furnishes but scantily the total quantity of the protein must be increased until the particular want is met. When this condition is realized there will be an excessive offering of other amino-acids for which the organism has no distinct use.

In the light of what has been said it should not be surprising to learn that some proteins are much superior to others when the judgment is based on the minimum amount serving to keep a subject from loss of tissue. Generally speaking, the proteins of meat excel those of vegetable origin in their ability to maintain the nutritional balance with economy. But the proteins of rice, milk, and potato are nearly as good. Larger quantities of the proteins of wheat and beans must be fed to secure the same result, while the proteins of Indian corn are among the most wasteful which have come under observation.

It is important that the implications of what has been stated shall not be misunderstood. The facts were ascertained through experiments in course of which volunteers were restricted to one type of protein at a time. We do not commonly limit ourselves in any such a way. Because it takes a great deal of the proteins

from corn to meet the needs of the system we are not to conclude that corn is a poor food. It may be one of the best possible to mix with some other which will give quite different percentages of the amino-acids. Moreover, if we admit financial considerations it will be necessary to bear in mind that much more of the cereal proteins can be had for a dollar than of those in meat, milk, and eggs.

Urea.—We usually eat much more protein than is absolutely necessary. Even if we do not, there are bound to be amino-acids in the circulation for which there is no present demand. These are not wasted altogether. The nitrogen which they contain is withdrawn from their molecules, not as an element but in the compound *urea*. This is a soluble, non-irritating compound which is excellently adapted to be the chief nitrogenous excretory product. Much of it is formed in the liver, but much is also manufactured in the tissues at large. It circulates until removed from the blood by the kidneys.

After the formation of urea has been accomplished the residue of the amino-acid molecules seems to have a history identical with that of carbohydrate in the metabolism. In fact a considerable part of the proteins we eat seems to exist later as sugar. Hence there is a possibility of glycogen formation from protein and, as previously suggested, possible transformation into fat of some of the protein sugar. In diabetes the sugar formed from protein comes to light and makes its appearance even in fasting when the proteins of the body are being consumed. It will be realized that a diabetic suffers not only from the loss of the power to utilize carbohydrates, but is deprived to a great extent of the support of protein. When, at the last, he can no longer oxidize fat successfully the problem of his nutrition is hopeless.

To work over the amino-acids in such a way as to separate urea from them and then to turn the remainder into dextrose may seem a roundabout and costly mode of getting sugar. This is a fair argument against the over-

consumption of proteins, but, on the other hand, since there are bound to be amino-acids not needed for synthetic uses it is clearly better to make fuel of them than to reject them wholly. If a man pulls down an old house and builds a new one out of the timbers he is pretty sure to have many misfit pieces. It is the part of common sense to throw these into the cellar to be burned when desired. The body is operated according to the very same principle. The analogy may even be made to suggest the rejection of urea in the preparation of fuel. We have only to picture the householder as detaching the bolts, angle-irons, and other metal from the fragments which he throws upon his wood-pile.

We have distinguished between adequate and inadequate proteins. Recent investigations have shown that a three-fold classification is more precise. Some proteins are obviously insufficient, gelatin being an example. Some answer for the maintenance of weight but not for growth. The proteins of the highest order are those which will promote the growth of young animals.

CHAPTER XXIII

EXCRETION

The waste of the body consists mainly of highly oxidized products. If the economic ideal were attained these products should represent no potential energy. The major ones do not, but some of the minor ones are susceptible of further oxidation. Carbon dioxid is the foremost product of the metabolism and its removal from the system has been discussed in the chapters on Respiration.

Water.—Water occupies a peculiar position since it may be claimed that it is both a food and a waste. All the water that is taken into the body—neglecting that portion which may be added to the tissues during growth—will be discharged again. The total output will normally be larger than the intake, for the water that passes into and out from the body has united with it, at the seat of respiration, a moderate amount of water formed by oxidation. This smaller quantity has, of course, no quality to distinguish it from the greater volume of water in which it is merged. At times when the body is gaining water there may be no excess of outgo over income. Water, while in part a waste-product itself, is most useful as a bearer of other waste in solution. It figures thus in the urine and to some extent in the perspiration.

The chief ways by which excretion can go on are four: by the breathing, the urine, the feces, and the sweat. The order can be defended on the ground that obstruction of the breathing is more immediately fatal than suppression of the urine, while this in its turn is more serious than the failure of intestinal elimination. Contrary

to popular belief, the secretions of the skin have the slightest share in the total work of excretion. The great value of the sweat glands is not at all in connection with the removal of waste but in the dissipation of heat.

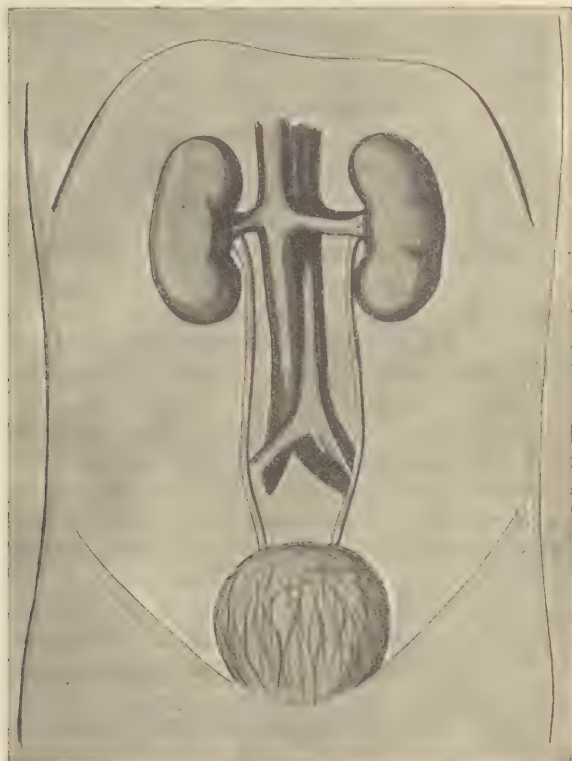


FIG. 73.—The kidneys and the urinary bladder. The two kidneys are shown within an outline which suggests the body cavity. Their advantageous connections with the chief artery and vein of the system are indicated. Below is the bladder reached by the two ureters. These vessels enter the bladder low down and behind—not at the level where they disappear from the figure.

The expired air carries out from the body nearly all the carbon dioxid and a rather large volume of water, some-

times as much as a pint in twenty-four hours. The kidneys often discharge as much as 3 pints of water in the same length of time. Dissolved in it is the larger part of the mineral matter requiring to be eliminated. More important than this is the presence in the urine of compounds of nitrogen, sulphur, and phosphorus, the distinctive end-products of protein decomposition. The chief of these bodies is the compound urea which was mentioned in the last chapter. Experience indicates that students must be cautioned against using urea and urine as synonyms. Urea is the leading substance in solution in urine, but the two words are not interchangeable.

The waste from the intestine is not easily defined. It is of a miscellaneous character; the bile pigments in a modified form are examples of excretions passing from the body by this route. The water loss from the alimentary canal is normally small. As to the skin, the perspiration is approximately a mineral secretion containing little dissolved matter besides common salt. When it is profuse it may carry in very small amounts organic waste-products like those of the urine. These are somewhat increased when there is kidney disease, but the skin can by no means compensate for the loss of the renal function.

The Work of the Kidneys.—We have now to enlarge upon the work of the kidneys. These are paired organs placed to the right and left of the vertebral column just below the diaphragm. The aorta and the inferior vena cava pass between them. A large but short artery leads from the aorta to either kidney; a corresponding vein connects each kidney with the vena cava. Thus the kidneys are in a position which favors a copious flow of blood through their vessels. A short cut or shunt for the blood is opened through them. Their actual blood-supply in proportion to their mass is exceptionally large. It is said to be exceeded in only one organ, the thyroid gland.

The microscopic details of the kidney are of such com-

plexity that we shall not undertake to present them. The secreting units are long and tortuous *tubules* originating near the surface of the organ and conducting the urine toward a cavity in the concave border. A funnel-shaped appendage receives the urine and it passes on into the *ureter*, a slender and delicate yet definitely contractile vessel. The muscular elements of the ureter are of the smooth variety and they execute a true peristalsis. The travelling contractions propel the urine in small quantities to the *bladder*.

This is a contractile sac placed in the pelvis in front of the rectum. The two ureters enter it low down and behind. Their openings are not far from that through which the urine escapes to the exterior. This passage is the *urethra*. The three openings are at the angles of a small triangle which is not much disturbed by the alternate enlargement and contraction of the bladder. We have used this organ before (Chapter IV) to illustrate what is meant by change of tone. When it has just been emptied it is quite inconspicuous and its upper surface is practically in contact with its base. When it is full it is rounded up and its walls are thin as though stretched. Yet, as we have insisted, we must not think that they are really stretched unless the condition is extreme; they have relaxed or lost tone and are not necessarily reacting with much pressure upon the liquid inside.

The bladder is often involved in reflexes. It is apt to contract when the hands are dipped in water. The urethra is controlled by muscle, both striped and smooth, acting on the principle of a sphincter. When this sphincter is voluntarily or otherwise inhibited, the urine enters the passage and seems to evoke a reflex contraction of the bladder which rapidly completes the discharge. Extra pressure may be thrown upon the bladder by contracting the abdominal muscles.

The Urine.—Some characteristics of the urine may now be pointed out. Its color is due to the carrying over to the kidneys of substances having their origin in the liver

and related to the pigments of the bile. The color is deepened in jaundice when the escape of the bile pigments by the normal channel is interfered with. It more commonly varies with the degree of dilution. After lively perspiration without water drinking the urine is apt to be high-colored, its dissolved solids being held in a small volume.

The urine of man when fresh is acid by ordinary standards of measurement. It becomes alkaline on standing because of the bacterial fermentation of urea with formation of ammonium carbonate. When this change is advanced an ammoniacal odor develops and a cloudy deposit may appear. The sediment noticed under these conditions is nothing abnormal. The urine of herbivorous animals is alkaline even when fresh unless the animals are deprived of food. It then becomes acid and the metabolism will naturally have changed to a carnivorous type, the animals living at the expense of their own tissues.

With an average diet we may expect that about seven-eighths of the nitrogen represented by the compounds of the urine will be in the form of urea. The remainder is divided among several waste-products all more complex than urea and not profitably to be discussed without the assumption of a knowledge of organic chemistry. One of these minor bodies is uric acid, a substance distinguished by its scant solubility and consequent tendency to be retained in the tissues. Some is inevitably formed in the daily metabolism, but the amount can be kept down when desirable by temperance in protein feeding and especially in the consumption of meat.

All proteins contain sulphur and some contain phosphorus. Accordingly, when they disintegrate in the body these elements have to be removed. Like the nitrogen they do not go free but in combinations, the sulphur in several forms but chiefly as sulphates, the phosphorus almost wholly as phosphates. These salts occur in urine together with a considerable amount of

sodium chlorid (common salt), and it is well to emphasize the essential difference between the history of the phosphates and sulphates on the one hand and the chlorids on the other. The former are oxidized products of proteins; the chlorids are like most of the water of the excreta—merely matter which was previously received in the same state. When no chlorids are fed the elimination is soon reduced to a very low level.

The *quantity of the urine* is influenced by many factors, but most radically by the amount of water taken and the varying activity of the sweat glands. A hot day is likely to mean a contracted urine, but some people drink enough extra water in warm weather to provide for a good volume in spite of the large quantity passing out through the skin. A sudden cooling of the body with a check on the perspiration can be depended on to increase kidney activity. This is most striking when one leaves the hot land and goes to sea on a summer day.

We must not assume to judge of the actual work done by the kidneys by observing how much urine they secrete. It is altogether probable that these organs are most severely taxed when they have to remove from the blood a maximum of dissolved solids in a minimum of water. In other words, concentration rather than volume must be our criterion. Average urine is two or three times as concentrated as the blood from which it is derived. Students of physical chemistry tell us that the separation of two liquids of unequal concentration requires the application of energy in perfectly definite and large amounts. The implication is that we shall favor the kidneys by diluting the urine so that it shall not so markedly surpass the concentration of the blood.

The precepts of renal hygiene are few and plain. Drink plenty of water. Do not eat protein foods to excess. Do not eat a great deal of salt. It is not so easy to apply these directions for there is no agreement as to the protein standard or how much salt is "a great deal." The protein question will be given further attention.

We have learned that some glands are very clearly under the command of the central nervous system while others are influenced more particularly by the changing volume of the blood-stream which penetrates their vessels. The kidney is a gland of the latter type. Its activity is usually in proportion to its blood-supply. A general rise of arterial pressure will drive the blood more rapidly than before through the renal capillaries and the response is likely to be prompt and considerable. The explanation of the influence of cold upon the kidneys can probably be explained on this principle. There is first a constriction of the surface vessels. This may lead to a rise of pressure in the aorta and so to an accelerated kidney circulation. It is also possible that when the surface vessels are narrowed those of the deeper parts, including the kidneys, are dilated through nervous influence. In this case there might be no rise of aortic pressure, but the new distribution of blood would secure for the kidneys a larger share than before.

It may be said, in passing, that the sweat glands are under direct nervous control. While there is usually a correspondence between the degree of their activity and the blood-supply of the skin, this is not always true. We know that there may be cold sweating when the skin is pale and manifestly receiving but little blood. There is other evidence to the same effect: that the glands may produce much perspiration with a restricted allowance

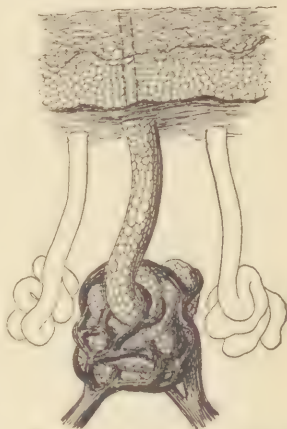


FIG. 74. —A sweat gland wrapped about with capillaries is suggested. It is shown as though there were no other structures below the skin up to which the sweat duct leads.

of blood and, again, may secrete less than usual when the skin is flushed and burning.

The Urine and the Metabolism.—Our statements thus far have been qualitative rather than quantitative. We must now begin to make some use of figures and it will be best to adopt metric standards. The gram will be our common unit of weight and if it is an unfamiliar one, the reader has only to bear in mind that about 28 grams make an ounce. It is desirable at this time to show what can be learned about the course of events in the body by analyzing the urine.

The datum most often sought is the quantity of nitrogen contained in the day's urine. We use this figure to estimate the amount of protein which has been decomposed in twenty-four hours. This involves at least two assumptions: first, that all the nitrogen excreted by the body is to be found in the urine and, second, that all the decomposition products of protein reach the exterior quite promptly. The first assumption is not strictly justified for there is an appreciable loss of nitrogen in the feces and a slight one through the skin. The second supposition, too, may not be wholly allowable, but so long as we are content with approximations we may regard the nitrogen of the urine as the *index of protein metabolism*.

Suppose that the urine for the day contains 12 grams of nitrogen. Nitrogen constitutes about 16 per cent. of an average protein. To see how much protein must have been destroyed to yield 12 grams of nitrogen we divide 12 by 16 and multiply by 100 or, what is the same thing, we multiply 12 by 6.25. Our answer is 75 grams. The subject under observation has therefore lost at least 75 grams of protein during the day of the trial. He may have lost 5 or 10 grams more than this owing to the escape of minor quantities of nitrogen in the feces and the sweat. These are figures of average magnitude for American students.

Nitrogen Equilibrium.—We cannot analyze the food which a man eats, but we can analyze some more that

closely resembles it. If such a check as this has been kept upon the diet of our imaginary subject it will probably be found that the nitrogen of the income has been very nearly the same as the nitrogen of the outgo. Furthermore, if we were to continue the experiment for several days and take pains to vary the nitrogen of the food supply as widely as possible we should find that the excretion would adjust itself to the changes in the diet with but little lag.

At one period of our investigation we might encourage the eating of meat, eggs, and legumes to insure a high-protein ration. We should find that if 30 grams of nitrogen could be tolerated nearly as much would reappear in the urine. The other extreme would be reached with nearly non-nitrogenous diet. This has been closely approached by feeding nothing but corn-starch pudding with cream and sugar. In this case we should not have the customary equilibrium for there would still be a definite output of nitrogen in the absence of income. But within very wide limits the body excretes just about as much nitrogen as it receives.

The facts ought to be intelligible in the light of what has been said about the way in which the organism deals with proteins. It has been pointed out that the requirement of amino-acids for synthetic service is a very moderate one. No matter how greatly we exceed it we find that the system responds continually in the same fashion: it sets aside for excretion all the surplus nitrogen. Hence the balance is generally struck between the food and the excreta unless the income is distinctly deficient. Retention of nitrogen occurs during growth and in the related conditions of recovery from fasting, convalescence from illness, and in pregnancy.

As we can calculate the protein decomposed from the nitrogen excreted, we can equally well calculate the storage of protein in the body of growing animals from the quantity of nitrogen retained. If, in the course

of a week or two, an animal has received 20 grams more nitrogen than it has given back to its environment the inference is that it has synthesized from the products of digestion (20×6.25) or 125 grams of new protein. If this were all represented by muscle the total would be about 625 grams, for muscle is about 75 per cent. water and contains perhaps 5 per cent. of other non-protein matter, in other words, one-fifth of it is protein. The increase in weight of a growing organism will accordingly be several times as great as the protein storage. It must add water and mineral salts to make new tissue and it is likely to add some fat.

It will be apparent also that when nitrogen is lost from the body, as in fasting, the weight must fall by an amount many times greater than that of the nitrogen excreted. The reasoning is parallel to that employed above: a loss of 1 gram of nitrogen means a loss of 6.25 grams of protein, and this in its turn stands for the destruction of perhaps 30 grams of average tissue. A fasting animal will therefore excrete an amount of water which cannot be accounted for on the basis of income or oxidation; it is water set free by the dissolution of tissue. This is a fact often overlooked.

The composition of the urine depends more upon the protein intake than upon any other factor. It will be well to emphasize just here a negative statement, namely, that the proportion and quantity of the urinary constituents are but slightly influenced by muscular activity. This is the same as saying that protein decomposition is not materially increased by exercise. The observation is an interesting one because muscle is so largely made of protein that early writers naturally assumed that this kind of material must be sacrificed in the act of contraction. It has become clear that in our consideration of muscle we must distinguish between the machine and the fuel. The machine is constructed chiefly of proteins (with water and salts), but the preferred fuel is sugar, with fat also available.

Normal urine, as we have seen, affords a basis for the estimation of nitrogenous metabolism. Abnormalities in the working of the body are often registered by this secretion. The significance of sugar has been dwelt upon but may here be restated briefly. A transient occurrence may result from eating much sugar and is not a sign of disease. If sugar is often present and in some quantity the suggestion is that the body lacks the full power to oxidize this food. Under such circumstances the reduction of carbohydrate in the diet for a while is often beneficial. In fully developed diabetes little or no sugar is oxidized and glycosuria is continuous. Not only the dextrose formed from the carbohydrates of the food, but much that is attributed to protein sources then comes to light.

• **Emotional Glycosuria.**—It has lately been shown that sugar may be found in the urine of entirely healthy subjects after an emotional strain. This has been noted, for example, in students who have taken hard examinations and in athletes who have either played in crucial games or waited to be called on as substitutes. The relation between the nervous system and the observed result is somewhat indirect and may be referred to later on. For the present purpose it may be said that during excitement influences are brought to bear upon the liver cells which lead to the transformation of much glycogen into sugar. This newly formed sugar enters the circulation creating a condition of hyperglycemia which, as we have already learned, will cause some leakage of sugar through the kidney substance.

In the urine of the diabetic there will be found, in advanced cases, not only sugar but an overflow of the acid products of an imperfect fat metabolism. These poisons are collectively known as the *acetone bodies*. Protein itself (albumin) frequently makes its appearance in the urine and is often, though not by any means always, associated with disease of the kidneys. Let it be repeated that diabetes is *not* a kidney disorder.

CHAPTER XXIV

INCOME AND OUTGO

The main facts about the changes intervening between the absorption of food and the discharge of the corresponding waste-material must now be clear. If we disregard the processes of growth and think of our food as fuel we can say that it is oxidized, either promptly or after a period of storage, and that the chief end-products are carbon dioxid and water. Protein stands somewhat apart for it yields compounds of nitrogen and sulphur in addition to the others.

We have seen that a study of the urine throws much light upon protein metabolism but very little upon that of other types of food. If we are to learn anything about the quantity of carbohydrate and fat subjected to oxidation we must use an apparatus that will arrest the carbon dioxid escaping from the lungs. Such an apparatus is difficult to construct and operate, especially if it is on a scale to deal with the human body, but several laboratories have been fully equipped for this line of work. Sometimes it is desired to include the excreta of the skin but often this is unimportant.

A short description may be given of what is called a *respiration chamber*, a device to collect the products in the expired air together with those from the skin. The subject is confined in an air-tight compartment. This may be in the form of a long box in which one must lie as in a berth or it may be more spacious. A man has remained for two weeks in a chamber of the largest kind. Air is pumped from the compartment at one place and returned at another. The stream maintained by the pump is treated as we shall now explain.

The air which is making the circuit outside the chamber is first driven through a jar containing sulphuric acid. This removes from it all moisture. The acid is gradually diluted by the addition of water brought from the

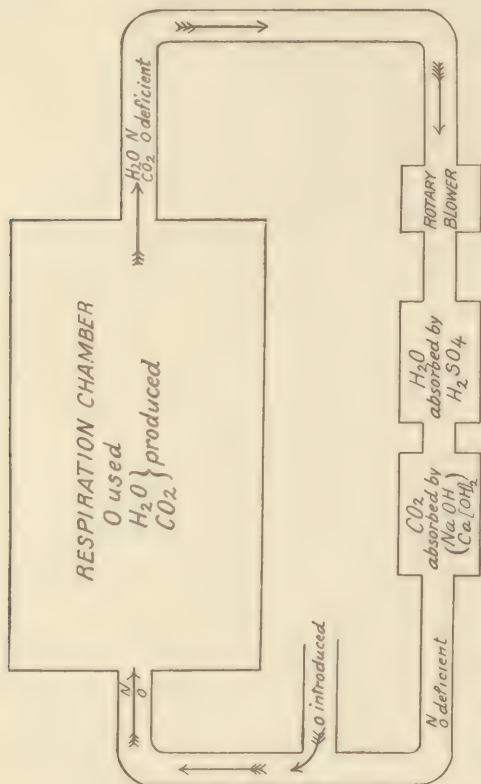


FIG. 75.—Diagram of circulation of air through respiration apparatus. (Atwater and Benedict.)

chamber and gains weight in proportion as this water is added to it. The weight of the container is determined at the beginning of each experiment and by weighing it again at the close the amount of water swept out by the air current can be estimated. This water has come

partly from the breathing passages and partly from the skin of the imprisoned volunteer.

The dry air from the sulphuric acid still contains the carbon dioxid which it has gained through being respired. To remove this it is conducted through a container in which alkali is used to retain the carbon dioxid. Special precautions are taken to hold back the moisture which might be carried out of the alkaline mass at this point. The gain in weight registered by the alkali cylinder during an experiment is taken to equal the output of carbon dioxid. The air thus freed from water and carbon dioxid is returned to the chamber.

It will be recognized that the scheme, so far as it has been described, keeps down the humidity and the carbon dioxid in the air breathed by the subject but does not compensate for oxygen consumed. This is secured as follows: A tank of pure oxygen is at hand and connected with the chamber. As the oxygen originally available is diminished by respiration and the resulting carbon dioxid is absorbed by the alkali the volume of the air in the compartment will tend to contract. By an automatic arrangement any measurable shrinkage of the air in the apparatus will automatically admit oxygen from the tank, while the admission will cease as soon as the initial volume and density have been restored.

The oxygen tank is weighed from time to time. The diminution in weight indicates how much oxygen has passed into the chamber to take the place of that consumed by the subject. So, with a chamber of this pattern, three figures are obtainable: the water loss, the carbon dioxid elimination, and the oxygen consumption. If the urine and the feces are collected for the same period we may consider that we have a fairly complete knowledge of the body's discharges. Of course, the task is much less simple than it has been made to appear. There are preliminary and subsequent analyses of the

air in the chamber which have to be carried out, and there are other details which we have not enumerated.

The Energy of the Metabolism.—We may look at the income and outgo of the body from the standpoint of energy as well as from that of matter. The food, looked upon as fuel, represents a definite amount of potential energy. The excreta represent very little. For any discussion of the facts we must have a unit for the measurement of energy and the one most used is the large Calorie. This is primarily a heat unit but we know that all forms of energy are convertible and we can make the Calorie stand for work or for electricity if we choose. The body generally disperses practically all its energy in the form of heat and so the unit is evidently the best possible. A large Calorie is the amount of heat required to raise the temperature of a kilogram (1000 grams) of water 1°C.

Oxidizable compounds of a uniform composition are said to have definite *fuel values*. The fuel value of a compound is expressed as the number of Calories set free by completely oxidizing 1 gram of that compound. One gram of sugar oxidized to carbon dioxide and water without by-products gives nearly 4 Calories. Starch has a value very slightly in excess of that of sugar. One gram of fat gives much more, say 9.3 Calories. The fuel value of alcohol is about 7 Calories. These figures do not seem to vary whether the oxidation is a literal burning or a physiologic decomposition in the body cells.

The case of protein is peculiar. One gram of protein burned in the open with a full supply of oxygen gives nearly 6 Calories. It contributes less than this quantity of energy to the organism for it is less completely oxidized in the life process than it can be by flame. Such products as urea have a moderate fuel value and represent energy which the body has failed to extract. They remind us of the cinders left by a coal fire. The actual fuel value

of protein to the body is a trifle over 4 Calories. It is nearly the same as that of the carbohydrates.

Calorimetry.—A calorimeter is an apparatus for measuring the evolution of heat. It may be adapted to show how much heat is given off by samples of food or other substances when burned in oxygen. It may be of a form to hold a living animal or even a man and to give us data in regard to the evolution of heat that accompanies the metabolic process. A respiration chamber such as has been described may be a calorimeter also. When it has this feature we can obtain simultaneously the material and the dynamic output of the inmate.

In some of the early and crude attempts to find out how much heat issues from the body of an animal the estimates were based upon observing how much ice could be melted at the expense of the metabolism. This involved chilling the animal and has been abandoned in favor of better methods. Sometimes the heat is reckoned by recording the rise of temperature in a volume of air which is exposed to the animal's influence. In other cases the heat is absorbed in a known mass of water and the calculation based on the extent to which the temperature is raised. This is the principle followed in the great calorimeters applicable to the human subject.

It is important to understand that not all the energy produced in the course of the metabolism results in heat that is directly measurable. The most considerable exception is found in the disappearance or making "latent" of a large quantity of heat through the evaporation of water. A man in a respiration chamber may easily evaporate a liter (1000 grams) of water in twenty-four hours. This change in so large a mass of water from the liquid to the gaseous state entails the apparent annihilation of heat to the amount of more than 500 Calories. (It is not really annihilation, however; the heat becomes tangible again when the vapor is condensed.)

A man in a calorimeter, therefore, gives out a certain quantity of heat which can be deduced from the warming effect on water circulating in coils and he is credited with having produced an additional quantity which is estimated by ascertaining how much water has evaporated from his skin and respiratory tract. We have said that the latter quantity may be as much as 500 Calories. The total will probably approach 2000 Calories for a resting adult. If the body temperature is not the same at the end of the experimental period that it was at the beginning a correction has to be made for heat retained or dissipated, as the case may be. For example, if the body is equivalent to 50 kilograms of water as a container of heat, and its temperature has risen 0.5°C . during the experiment, 25 Calories must have been stored in it. This must be added to the other quantities to arrive at a correct estimate of the heat produced.

The total daily production of heat by a full-grown man is not likely to fall below 1500 Calories under any circumstances that can be called normal. The maximum is in the vicinity of 10,000 Calories. These limits are so widely separated that one seeks at once for a determining condition and will probably draw a correct inference as to what it is. No other factor influencing metabolism approaches in importance *muscular activity*. The heat production is nearly proportional to the work performed. It is also true that the discharge of carbon dioxid varies in the same sense. Since, as we have already found, the excretion of nitrogen has no such rise and fall we have here clear evidence in support of a previous general assertion: that muscular contractions are made at the expense of non-nitrogenous fuel.

Someone may raise the question, does the calorimeter give credit in Calories for energy expended in the performance of mechanical work? It may be answered that it does excepting under special conditions. Suppose, for instance that the subject of an experiment engages in sawing wood. The ultimate result of his

efforts is merely heat production through friction. Or take the case of his heart: this organ impresses energy upon the blood but it is all turned back to heat as the resistance of the vessels is overcome. In the same way, the work done by the breathing muscles is rendered to the calorimeter as heat, for the weight which is lifted is allowed to sink back again at every expiration and there is no storage of potential energy.

If the man in the chamber should operate a force pump and permanently elevate a quantity of water to a tank overhead some of his energy would actually fail to appear as heat. This would illustrate one of the "special conditions" referred to in the preceding paragraph. The general principle is that a man in a calorimeter will receive credit for all the energy he expends in muscular work, provided that he does not produce lasting changes in his environment.

Indirect Calorimetry.—If a respiration chamber has not the appliances to make it a calorimeter it is still possible to estimate the energy production of the captive. We can calculate from his material output how much of the standard fuel substances he has decomposed and then we can assign to these their recognized calorific values. This procedure is known as indirect calorimetry. It will be worth while to give a rough idea of how this is done.

Our data are (1) the nitrogen excretion; (2) the carbon loss, and (3) the oxygen consumption. We do not need to know the water outgo in this case. The calculation of the protein metabolism from the nitrogen is a step we have already taken. We will assume, as once before, that the protein decomposed amounted to 75 grams. This should have furnished a trifle more than 300 Calories. The carbon loss has been mainly in the respiratory carbon dioxide but our total must include the small quantity in the urinary compounds. Suppose that the total is 250 grams. We must deduct from it the carbon in 75 grams of protein, about 39 grams. The

remainder, 211 grams, stands for carbon from carbohydrate and fat.

One would say that we had now come face to face with a hopeless difficulty. How can we assign to each of the two types of non-nitrogenous fuel the proper share of the carbon? There is nothing individual about their end-products. The division of the carbon into these portions is, in fact, too difficult to explain in detail. But the means of guidance is furnished by the oxygen consumption. The amount necessary to oxidize a gram of fat is different from that needed to oxidize a gram of sugar. When a certain quantity of oxygen is known to have been used to release a certain quantity of carbon dioxide the expert in nutrition has no trouble in solving equations that show how much fat and how much sugar have been used.

Let us suppose that in our hypothetical example the 211 grams of carbon from non-protein sources is found to represent 91 grams of fat and 350 grams of carbohydrate. (These are possible figures.) We can go on to say that 91 grams of fat should have given rise in its decomposition to about 845 Calories, while 350 grams of carbohydrate should have yielded about 1400 Calories. Adding:

Calories from protein.....	300
Calories from fat.....	845
Calories from carbohydrate.....	1400
Total.....	2545

When a man is in a calorimeter which is also a respiration chamber we have the interesting possibility of comparing the heat which he actually produces with that which he should theoretically evolve—direct with indirect calorimetry.

The figures obtained are in close agreement. This means that the living organism produces no measurable energy which cannot be accounted for as derived from

the consumption of fuel. It is, in effect, the demonstration that the body is strictly subject to the principle of the conservation of energy. An alcohol lamp can be substituted for a man and the calculations of direct and indirect calorimetry carried out upon it with parallel results. If we had found that a man could produce 3000 Calories when his fuel consumption entitled him to only 2000 we should have concluded that the living state conferred upon matter the ability to *create* as well as to *transform* energy.

The fact is to be pressed home that we can judge of the metabolism with great accuracy by analyzing the excreta but not by fixing our attention upon the day's ration. There is a presumption that the food will correspond in quantity and proportion with the material metabolized but this is only a presumption. We have only to consider that the income may be *nil* and the metabolism large, as when a starving fisherman rows for his life. Over long periods there must, of course, be an approximation of the diet to the metabolism. The observation that the daily ration of a Maine lumberman has a value of 7000 Calories or more is a fair indication that the output of energy is of the same order, but we cannot assume a close correspondence upon a single day.

There have been many studies of the diets chosen by various classes of people. Men who do hard work commonly secure a supply of 3500 Calories or thereabouts. This is the figure for farmers in widely separated countries. The active, growing boys at St. Paul's School, Concord, N. H., have been found to surpass the farmers. Their daily demand is for about 5000 Calories. The ration of sedentary individuals may be 2500 Calories or even less. Advocates of low feeding have urged that these allowances are too liberal and may be reduced with advantage by 500 Calories or so. It does not appear that many people have departed greatly from the average practice of the race, unless for rather short periods. We shall refer to this question again.

When we speak of the calorific value of a ration we are assuming perfect absorption. Of course this involves an error but not a large one. One often hears the suggestion that a certain person "gets more of the goodness from his food" than does another. There is little evidence in support of this judgment unless the second individual is a victim of chronic diarrhea. Lecturers and writers may carelessly assert that it is possible by some system—prolonged mastication, it may be—to improve the assimilation "by 50 per cent." or "100 per cent." The ordinary efficiency of the digestive system is such that an improvement of 3 or 4 per cent. is the most that is even conceivable.

Proportions of the Foods.—It has been said that the free selection of foods to supply the needs of the day is likely to lead to the inclusion of about 75 grams of protein. The foods chosen will usually give about the proper number of Calories, and since 75 grams of protein furnish a little over 300 it will be seen that an average of about 2000 Calories must be represented by carbohydrate and fat. The fat in freely selected food will not often exceed 100 grams a day. It will in many cases be much less, perhaps no more than 50 grams. The calories from 50 grams of fat will be about 465, from 100 grams about 930. In round numbers, then, the carbohydrates of the ration must furnish from 1000 to 1500 Calories. From 250 to 375 grams of starch and sugar will answer the purpose.

The following combination may be considered a common type of ration:

Protein.....	75 grams or	300 Calories.
Fat.....	50 grams or	465 Calories.
Carbohydrate.....	375 grams or	1500 Calories.
Total.....		2265 Calories.

An indefinite number of combinations can be suggested in which the protein and the total Calories shall be constant. If, for example, the fat is increased to 100 grams we may have the items as below:

Protein.....	75 grams or	300 Calories.
Fat.....	100 grams or	930 Calories.
Carbohydrate.....	250 grams or	1000 Calories.
Total.....		2230 Calories.

We have not been at pains to keep the total precisely the same. We are using only approximate figures for the heat values of protein and carbohydrate so that there would be no point in refining other parts of the calculation.

Once more, there is the possibility of the inclusion of alcohol in the diet with some reduction of the other non-nitrogenous foods. This may now be indicated:

Protein.....	75 grams or	300 Calories.
Fat.....	90 grams or	837 Calories.
Carbohydrate.....	230 grams or	920 Calories.
Alcohol.....	25 grams or	175 Calories.
Total.....		2232 Calories.

When a ration is increased to meet the requirements of heavy muscular work there is not likely to be any great addition to the protein fraction. The extra Calories are obtained from fats and carbohydrates, the latter bearing the brunt of the demand. Among the most surprising statistics of diet are those regarding the huge intake of patients fighting tuberculosis. The daily protein may exceed 200 grams, the fat 300, and the carbohydrate 500, with energy totals in the vicinity of 5000 Calories. The wasting of the tissues in this disease can only be compensated by a protein supply which in health would be considered most unhygienic.

Conditions Affecting Metabolism.—We have rightly given the foremost place among the factors that determine the amount of the metabolism to *work*. When we say that *exposure to cold* greatly increases the oxidation it might seem that we were introducing another factor, but we are really instancing what is merely a

special case of muscular activity. The simple fact is that cold leads to an increase in reflex tonus, to shivering, and to instinctive briskness of movement. The result is thus a form of exercise.

The change from fasting to feeding influences the metabolism much less than might be anticipated. It is true that a fasting animal will usually be found to have a low metabolism but this is because it is disposed to be quiet. If it is given food, and remains as inactive as before, the increase in oxidation will be very moderate. It is not likely to exceed 20 per cent., whereas mild muscular activity will double the original quantity. The tendency of protein food to increase the metabolism is much more marked than that of the non-nitrogenous types.

Changes in the state of the tissues and fluids of the body as a result of the altered activity of certain organs may considerably change the total metabolism. This is particularly true of the thyroid gland, a structure which will be more fully dealt with by and by. The general statement may be made here that abnormal activity of the thyroid means a high rate of decomposition among the stores of the body. Accordingly, people with overactive thyroids become emaciated and the extract of the organ is often used in patent medicines intended to reduce weight. Deficient thyroid activity may help to cause obesity in certain cases, the oxidation in the tissues lagging behind the assimilation of new material.

Small animals have a greater average metabolism, weight for weight, than larger ones. This is true whether we have reference to the young and adults of one species or to the adults of two species, as mice and rats. It has been shown that the metabolism is more nearly proportional to surface than to weight. It is a principle of geometry that the smaller one of two solids of similar form has more surface in proportion to its mass than the larger. If a mouse is *half* as long as a rat and of

the same build it will weigh about *one-eighth* as much, while it will have *one-fourth* the surface of the larger animal. Its metabolism under comparable conditions will be nearer one-fourth than one-eighth that of the rat.

So a baby a year old and weighing 20 pounds will probably have a metabolism of more than twice as many Calories per unit of weight as that exhibited by its parents. The rate will be fairly uniform for both when it is referred to surface area. Such comparisons are made at an external temperature high enough to

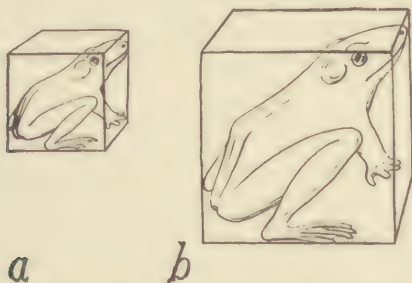


FIG. 76.—If a cube measures *twice* as much as another along one of its edges, it will have four times the surface and eight times the weight of the smaller. The same principle must apply to two animals if they are alike in build.

avoid the reflex stimulation of the skeletal muscles to which we have alluded. The area of the full-grown human body has been estimated at 1.7 square meters, and as the minimum metabolism is somewhat less than 2000 Calories the standard quantity per square meter appears to be about 1000, a convenient round number.¹ It does not vary much from this in several very unlike species of animals of the "warm-blooded" order.

If, instead of comparing a baby of one year with the adult, we had chosen a boy of ten or twelve, we should have

¹ According to certain authorities the surface is greater, about 2 square meters. This gives a daily value per square meter of 800 Calories or a little more.

found that at this age of active development the metabolism is definitely above the standard of maturity even when referred to a unit of surface. There has been a strong protest of late against the excessive importance attached to surface as the chief factor in determining the rate of heat-loss and so of heat-production.

Students are likely to question whether mental exertion noticeably increases the metabolism. Careful observations have been made upon this point and it may be said that any such increase is trifling. It can probably be said further that an increase noted in a man who is using his cerebrum is not due to extra oxidation in the gray matter but to a tension of the muscles unconsciously developed. We must bear in mind that the brain makes only about 2.5 per cent. of the total mass of the body, and that only a small fraction of it can be supposed to be the seat of the special activity attending intellectual work. Emotional excitement means a great increase in metabolism, but here again it is not cerebral oxidation which is registered, but the secondary activity evoked in muscles and glands.

CHAPTER XXV

THE REQUISITES OF THE DIET

In this chapter we shall include a summary and restatement of much that has gone before. We shall also have new material to add. If we begin the attempt to define an adequate diet we shall probably think first of the calorific requirement. If the specific case is that of a student taking a limited amount of exercise we may fix upon 2500 Calories as a fair standard. We must think next of the protein allowance.

The amount mentioned in the last chapter, 75 grams, is about what one is likely to take. The older statement that the average protein ration is 100 grams a day is not confirmed by recent reports. The protein should be from several sources. The unequal nutritive virtues of different proteins should be recalled. Proteins for growth may have ceased to be called for, but proteins for maintenance must still be supplied.

The non-protein part of the diet will be composed of carbohydrates and fats in proportions which may be widely varied. The usual tendency is to take both, but to make the greater use of carbohydrates. The Esquimaux exhibit the possibility of living on proteins and fats with a minimum of starch and sugar, but this course is forced upon them by necessity and does not indicate that it would be chosen instinctively. Their protein consumption is very great and we must remember that surplus protein becomes a source of sugar in the system. Since sugar must be at hand when fat is to be oxidized we may suppose that carnivorous men and animals are protected against acidosis because they take more protein than they appear to need.

At the other extreme from the Esquimaux we have the vegetarians of various classes. They are not likely to eat too much protein and they are sure of plenty of carbohydrate. When their diets are scientifically planned they often contain a goodly amount of fat secured by the use of nuts and vegetable oils. If milk and eggs are permitted the protein and fat can be more readily brought up to the standards of mixed diet. Eggs are like meat in their very low carbohydrate content.

Alcohol enters with considerable regularity into the diet of many. This is particularly true in Europe. As has been indicated before, it acts much like other non-nitrogenous food. According to a careful estimate, about one-fifth of the calorific requirement of the day may be met by alcohol without producing any suggestion of intoxication. That is to say, if 2500 Calories is the total called for, some 500 may be represented by alcohol. This means about 70 grams of the pure compound, an amount which might be conveyed in less than half a pint of whiskey, a full pint of a fortified wine like port, a quart of a light wine, or 3 quarts of beer. To say that it is possible to use alcohol to such an extent is by no means to advise it.

Isodynamic Quantities.—From what has been said it will be gathered that carbohydrate and fat are in a great degree interchangeable and that alcohol can be substituted for either within certain limits. We must point out that when substitutions of this kind are made the proportion is not gram for gram, but determined by calorific values. Thus a gram of fat has the available energy of about $2\frac{1}{4}$ grams of sugar. On the same principle it can replace $1\frac{1}{3}$ grams of alcohol. Quantities of different foods which have equal fuel-values are said to be *isodynamic*.

Water.—The services of water to the system should be evident by this time. It is necessary, first of all, to the normal constitution of the tissues. It makes up about 75 per cent. of most of them and about 65 per

cent. of the whole body. (The presence of the bones somewhat lowers the average.) These proportions cannot be much altered by the severest drafts upon the water of the organism. When it is reduced, even by a little, the secretions are diminished and thirst becomes imperious. It is plain from these facts that water is necessary to growth; it is as essential to new tissue as protein itself.

Water is necessary to maintenance as well as to growth because it must make good the losses from the body. These losses cannot be checked because the urinary excretion must have water as its vehicle and because much of the time water must be evaporated from the skin and the breathing passages to remove an excess of heat. The secretion through the skin falls to a low level when there is no call for it, but there seems to be no way to keep back the water that is taken by the respired air. This is a secretion which is never suppressed and, unlike most others, it is one which environmental conditions directly determine, the nervous system seeming not to regulate it at all.

Mineral Matter.—There is abundant evidence to show that living protoplasm cannot exist without mineral as well as organic constituents. It may be that while the living state continues these mineral substances—salts of sodium, potassium, calcium, etc.—are united with the proteins in temporary combinations. In fact, the materials which we call proteins as we handle them in the laboratory are not often “ash-free.” This means that they leave mineral residues when they are burned. Many experiments have proved that the thorough removal of ash from the food given to animals impairs its nutritive value.

The need of a mineral ration is naturally more distinct when growth is in progress than it is later. But it is usually stated that it never entirely ceases. The ash of milk has been laboriously analyzed and it has been found to show a marvelous fitness for the purpose it

must serve. Milk is made by the cells of the mammary gland. The antecedent materials are presented to these cells by the blood through the medium of the lymph. Yet the selective power of the gland tissue is such that the milk is radically unlike the blood in almost all its characters.

This is most strikingly true of the salts. In blood the leading saline compound is sodium chlorid. In milk this salt is sparingly present and calcium phosphate stands first. The lime has been derived from blood in which it occurs in only a minute percentage. While the ash of milk is utterly unlike that of blood or blood plasma, it is remarkably like the ash obtained by cremating the young animal entire. The high percentage of lime in milk answers to the need for developing a skeleton. The gland is not compelled to deliver a filtrate such as might be anticipated from a study of the plasma, but is able to prepare a secretion prophetic of a body which does not yet exist. One may well say of milk that it "is the substance of things hoped for, the evidence of things not seen."

One discrepancy between the ash of milk and that of the young animal has been reported: a deficiency in iron. But it has been shown at the same time that new-born animals have more iron for their weight than they will have later. It is thus normal for them to receive a food that is poor in this element for a while. Iron, by the way, is one of the indispensable elements. We cannot have hemoglobin without it and it is doubtless needed in other connections. It is best utilized when it is taken in the form of complex organic combinations. Among the foods which furnish it in appreciable amounts are meats, yolk of eggs, apples, strawberries, asparagus, and spinach.

Sodium Chlorid.—While food ordinarily contains a great variety of mineral compounds there is one which we deliberately add to our diet. This is common or table salt (sodium chlorid). As much as 10 pounds may be eaten in a year by a man of average tastes.

We hear of people who are said not to eat any, but such individuals must receive a moderate quantity even though they aim to avoid it; it is represented in most foods. The bulk of the salt which we eat is taken to improve the flavor of various dishes, but a certain amount seems to be a more fundamental necessity.

World-wide observation has shown that salt is generally prized by the vegetarian races but disliked by those that are approximately carnivorous. The animals which seem to crave it are herbivorous, cattle, sheep, and deer being among them. Cats and dogs show an aversion to meat that is noticeably salt. An explanation of these divergent instincts has been offered which is ingenious and apparently reasonable.

Salts of sodium and potassium are mingled in natural foods. In most cases the potassium compounds are in excess, but sometimes their preponderance is only moderate, while in other cases it is overwhelming. In meat the potassium does not so greatly exceed the sodium as it does in most vegetables. Potatoes, for example, are very rich in potassium and poor in sodium. It is argued that if the system is loaded with a large quantity of potassium salts the duty of restoring the composition of the blood to the normal standard must fall upon the kidneys. These organs will soon eliminate the surplus potassium, but while they are doing it they will let slip more or less of the abundant sodium chlorid of the plasma. A definite need for this salt will then arise.

An investigator has shown that eating much potassium has just the effect assumed. Experimenting upon himself he swallowed salts of potassium until he had taken on a single day the equivalent of 18 grams of potassium oxide. All this soon passed into the urine, but there was lost with it 7 grams of sodium chlorid for which the diet made no compensation. The total potassium intake in this experiment seems large, but it was not greater than might be ingested in a day by one living chiefly upon potatoes.

Stefansson, the Arctic traveller, has remarked the

dislike for salt exhibited by the carnivorous Esquimaux. When he first settled among them he was embarrassed by the demand that he should provide food for all comers. This was the social convention and he did not wish to violate it though his stores were threatened with rapid depletion. However, he found a happy solution of the problem: if he salted the food very moderately, merely to his own liking, his guests were content with a little. The requirements of hospitality were met and the provisions were conserved.

Organic Extractives.—We recognize in our food many minor substances mixed with the proteins, carbohydrates, fats, water, and mineral salts. These are called *extractives* or *food accessories*. Together with the salts they are responsible for most of the flavor of different foods and for nearly all the odors which make or mar our meals. Pure proteins, starches, and fats are practically tasteless. The sweetness of the sugars is about the only taste that can be discovered in the absence of the salts and extractives. Even the sugars and salts are odorless, so we have to conclude that the subtle and attractive qualities that differentiate between foods and appeal so strongly to the appetite are dependent on substances that we know little about and which form but a trifling total by weight in any diet.

We have learned that it is most important that food shall be appetizing. It is not mere gratification that is secured, but more efficient work on the part of the digestive mechanisms both motor and secretory. Enjoyment of a meal is generally a guarantee of good digestion unless the circumstances are quite unusual. We ought to eat what we like—though it may be suggested that it is desirable to extend the range of our liking. We may be able to worry down something that does not strike us very favorably and let it be digested by the juices that have flowed primarily in response to some more delectable article. Certain food accessories seem to deserve the designation of *secretagogues* already used in Chapter XIV.

Meat is peculiarly rich in extractive bodies. Among these are the ones which are most surely capable of arousing the gastric glands to activity. On the other hand, the extractives of meat are often condemned as adding needlessly to the work of the kidneys. Some of them are formers of uric acid, and it is desirable in many cases to keep the production of this refractory waste-product at the lowest possible level. Opponents of meat claim that these extractives are drug-like compounds tending to establish an irritable disposition and to diminish resistance to fatigue.

The stimulating principle in tea and coffee (*caffein*) is chemically allied to some of the extractives of meat. But it does not appear to give rise to uric acid and it has been shown to increase working power in a definite degree. The substance *theobromin* in chocolate and cocoa is related to *caffein* in composition and action but is rather milder in most of its effects. It is natural to suppose that any stimulant which favors a rapid expenditure of energy for a time will also induce a period of depression and sluggishness as a reaction. So it is a surprise to learn that the most skilled investigators have not detected any fall below the average normal condition when the initial effects of *caffein* have passed off.

Vitamins.—The extractives we have been discussing have been such as are favorable to some phases of physiologic activity but not indispensable. It has lately become probable that certain substances of this class are truly vital in their importance—that the nutrition of the body cannot be maintained without them. The name *vitamin* has been proposed for any such compound, though it is probably too specific. An amin is a nitrogenous body of a certain molecular type and the prefix emphasizes the idea that the one referred to is necessary to life. We do not know how many compounds there are which deserve to rank as vitamins. The list will probably be extended year by year.

Deficiency Diseases.—Long before the conception of vitamins was clearly presented it was known that

nutritional disasters sometimes resulted from restricted and peculiar diets. The records of explorers contained many references to *scurvy*, a distressing disease which prostrated many members of their parties when the food was limited in variety and not fresh. The victims of scurvy became very weak and suffered from intense soreness of the gums, loosening of the teeth, a tendency to hemorrhage, friability of the bones, and other symptoms. Certain articles, such as lemons, limes, potatoes, and fresh meat, gained the reputation of being *antiscorbutics*, that is, of preventing or curing scurvy.

It was formerly held that the foods causing scurvy had become in some degree poisonous through deterioration during long keeping. The good effects of the antiscorbutics were then explained as due to an antidotal action. But we are now inclined to regard scurvy not as a state of poisoning, but as a *deficiency disease*, the system being disordered for want of some particular supply. Assuming that one specific substance is lacking we say there is need of a *vitamin* and we believe that it can be conveyed in the various antiscorbutics. We speak somewhat inaccurately of the "vitamin of scurvy," meaning the vitamin in the absence of which scurvy develops.

It is well to add that a different view of the nature of scurvy has been advanced. This is to the effect that the trouble arises from a peculiar type of intestinal decomposition favored by such diets as have been associated with the disease. It seems possible that the essential feature in the breakdown is the destruction of some precious accessory substance. If this is the case, the new conception is not so far removed from the old as might appear.

Another deficiency disease is *beri-beri*. This is common in the far East, while a condition very much like it has occasionally been observed in this country. It used to be thought that beri-beri was an infectious disease, and the impression gained strength from the fact that it often raged where men were closely quartered, as in prisons and laborers' camps. But these were situations in which the diet was common to all and not of a varied

character. Better feeding has always stamped out beri-beri and cured all but the most advanced cases.

In the Orient the victims of beri-beri have usually been people subsisting largely on rice. The disease progresses through two stages. In the first there is steady loss of weight and strength. In the second there sets in a general neuritis, that is, an inflammation and degeneration of the nerve trunks. This is naturally most serious since it leads to sensory and motor paralyses of greater or less extent. Death may result or there may be lasting defects of sensation and motor control.

Beri-beri appears to be caused by the lack of a vitamin. The compound is one which has apparently been isolated and is not of great complexity. A neuritis like that of beri-beri can be induced in animals by restricting them to certain foods, and then overcome by adding to the diet a minute quantity of the pure vitamin. It is a most interesting fact that the husk or pericarp of rice furnishes the vitamin which is not present in the kernel. What is called "polished rice" has been freed from the pericarp and will cause something like beri-beri in pigeons if they are given nothing else to eat. After the symptoms are marked the birds can be restored to health by including the husks with the polished grains.

The so-called vitamin of beri-beri can be derived not only from the husks of rice but from meat, yeast, potatoes, and other sources. Any diet that is not severely limited in variety will be certain to afford it. It can be said of polished rice, as of gelatin, that it is not unwholesome but merely insufficient by itself. Either may be most valuable when associated with other foods.

The course of events when beri-beri is coming on has been analyzed as follows: The vitamin is primarily needed by the nerves. Some of it is present in other tissues as we may infer from the remedial virtue of meat. When none is supplied by the diet the gradual disintegration of the vitamin in the nerves is no longer compensated by the food. The need will be met for a while by abstracting the vitamin from other parts

of the body. But to remove any essential constituent, however small its amount, from a tissue is to cause the dissolution of that tissue. The integrity of the nerves is maintained temporarily but at a ruinous cost. It is as though a large and costly machine were to be dismantled merely to provide bolts and screws to repair another piece of mechanism.

The period during which the tissues in general are being sacrificed for the benefit of the nerves is that in which the loss of weight and strength is so marked. A time arrives when the internal supply of the vitamin as well as the supply from the diet is insufficient and the nerves can no longer be kept normal. The stage of neuritis is then established.

Other disorders besides scurvy and beri-beri are almost certainly to be classed among deficiency diseases and attributed to the lack of essential compounds in the ration. Nutritional difficulties in infancy may be examples of such conditions. There is at the present time much discussion as to whether the serious disease *pellagra* belongs in this class. It is agreed that it attacks, for the most part, people whose diet is monotonous and that liberal feeding favors recovery, but there is some evidence that it may be infectious. We cannot pass judgment here upon this question.

The recognition of vitamins gives concreteness to ideas that have long been held in a vague way. Many years ago Sylvester Graham urged that we should not carry too far the refining of food lest, in the discarded material, we lose something of value. The flour which bears his name was prepared in conformity with his teaching, including, as it does, the husk as well as the kernel. This was more than half a century before the observations concerning the pericarp of rice.

A shrewd criticism has been passed upon sugar: namely, that it is not a normal food because it has been so refined as to consist of only one compound. Native food products are always mixtures of numerous bodies,

however markedly one type may predominate. It does not appear that this argument should be given much weight, for we use sugar chiefly as an addition to other foods, but we can appreciate the suggestion that we are not yet wise enough to know just what list of compounds must be furnished for all the purposes of nutrition and which ones can be omitted. In default of complete information we ought to include as many as convenient.

Certain agitators contend that the best diet is one composed entirely of uncooked foods. It is doubtful whether a scientific foundation for such claims has ever been conscientiously sought. We may conceive that there are valuable bodies, perhaps deserving to be called vitamins, which are destroyed by heat of the degree used in cooking. In view of this possibility it may be conceded that we should eat a good deal of raw food. But the advantages of cooking in developing flavors, increasing the digestibility of many articles, and, above all, in sterilizing food which might be infected cannot lightly be set aside.

As it is possible that we may reject needed supplies by too much refining of our food and lose something of utility in the processes of cooking, so we may possibly lose vitamins when food is preserved too long. When we say that a canned product has lost its "goodness" we are apt to refer to flavor, but it is not unlikely that the gradual deterioration that goes on even in sterile food may rob it of some of its nutritive worth. But here again we may point out that a food which is not perfectly adapted to meet *all* the current needs may still minister to many of them and take its place helpfully in the diet. It cannot be condemned as poisonous merely because it has its limitations.

It is evidently much harder to compare one diet with another than has been commonly assumed in the past. Some of our American physiologists have reported the excellent results they have obtained with rations considerably below the older standards of quantity. English

critics have expressed surprise that the diets recommended have furnished no more protein and no greater fuel-value than the food of the very poor in London or the "punishment ration" of British prisons. We are not disposed to deny the force of this comparison, but we realize much more fully than we did even five years ago that quality as well as quantity must be taken into account in any such discussion.

We have seen that two rations may be equal in protein, as shown by ordinary analysis, and far from equal in their power to nourish. If the protein in one case is from meat or rice it will determine the superiority of that diet to one in which the protein is from beans or corn. We now see, in addition, that one ration may satisfy requirements not met by the other because of its minor constituents both mineral and organic. The vitamins must be supposed to arise as by-products of metabolism in the living matter which is destroyed to become our food; they cannot be obtained from proteins by mere digestion. Quite failing to modify the figures that represent quantitative composition, they still confer the most important properties upon foods which contain them.

Recent presentations of this subject tend to be cast in the following form. The valuable accessory substances of the diet are of two kinds. One kind is distinguished as "water soluble," and it is seldom entirely absent save from a few artificially refined foods, like sugar and polished rice. The second type of essential accessory is "fat soluble," and is best obtained in cream. It is furnished by other animal fats also, but more liberally by the fat of glands (*e. g.*, cod-liver oil) than by ordinary adipose tissue. Vegetable oils do not yield it at all freely, but it is obtainable in green plant tissue even though this is poor in fats. The highly suggestive statement has been made by an expert in nutrition that we need to eat *a definite amount of tissue that was recently the seat of active metabolism*, particularly such as is associated with growth. Green leaves and young tips have this character. Milk has similar properties, for it comes from intensely active cells.

CHAPTER XXVI

THE HYGIENE OF NUTRITION

In the last chapter it has been shown that the diet must conform to certain requirements. It must furnish sufficient protein and it must be adequate as a fuel supply. It has been shown that kind as well as quantity of protein must be considered. Obscure needs must be met by suitable offerings of extractive substances and salts. There must be plenty of water. It remains to speak of still other matters related to individual nutrition.

We need to remind ourselves that nutritional disturbances may arise from conditions not directly connected with the diet. Chief among these are mental states. A brief period of agitation may easily lead to an indigestion. From what has been said of the nervous government of the alimentary tract this should not excite surprise. The failure to enjoy a meal is likely to mean a failure of gastric secretion or at least a delay in its establishment. The motor reactions of the stomach may also be interfered with. When the gastric juice fails to make its appearance the food is decomposed by bacteria instead of being digested in the normal way. Products may be formed which are sufficiently poisonous to cause nausea, or the effects may be more in the line of gas formation with pain.

When the working of the system is upset the stomach contents may be retained for many hours instead of being passed to the intestine. When they do reach the lower part of the canal they are still subject to bacterial decomposition and the products continue to cause trouble. If the normal absorption is delayed, fermentation runs riot in the intestine and pain and flatulence are to be expected. If nitrogenous food reaches the

colon in unusual amounts, owing to deficient digestion and absorption at higher levels, downright putrefaction is encouraged. Poisons are generated which act upon the whole system after being absorbed into the blood. Their manifold ill effects are covered by the term *auto-intoxication*.

Some signs of this condition have long been recognized. They include drowsiness, headache, inertia, and ready susceptibility to fatigue. Other results are attributed to the state when it is persistent. Among these are nervous depression, anemia, troubles with the joints—popularly called rheumatism—and a disposition toward hardening of the arteries. It is easy to see that auto-intoxication tends to perpetuate itself. If it is set up as a result of a period of indigestion it may prolong the causal condition by depressing the spirits and enfeebling the reactions of the nervous system. Here is a good example of an effect becoming a cause and so acting as to intensify itself. This is what is known as a “vicious cycle.”

The system will generally rally from indigestion that has its origin in transient unhappiness, anger, or pain. When such moods are long continued as in grief, anxiety, severe disappointment, or intense homesickness auto-intoxication may become a fixed condition that will not remedy itself with the passing of the circumstances that were primarily responsible. The bacterial activities that are rife in the intestine may require something quite different from mental suggestion for their regulation.

We cannot avoid intestinal infections. The canal is sterile at birth, but never remains so for more than a few hours. Within a few weeks it harbors a countless host of microorganisms of many varieties, subsisting upon the food and secretions, multiplying, and perishing to undergo digestion like other organic matter. Billions or trillions of them, living and dead, are thrust out with the feces and yet the supply is maintained. It is not certain that man derives any advantage from

the presence of the intestinal bacteria but, on the other hand, in the majority of cases they are not known to harm him. Mischief may be done either by a general excess of bacterial activity or by the substitution of hurtful for innocuous forms.

Measures against Auto-intoxication.—We have suggested that this undesirable condition may result when the digestion has been retarded as a result of psychic factors. It may equally well follow disturbances set up in other ways. Overeating is probably a frequent cause. If the capacity of the canal to absorb all the food presented is overtaxed there will be residues to be decomposed. It is fortunate that in many cases of overindulgence a mild diarrhea is the most obvious sequel. Auto-intoxication is minimized by the vigorous sweeping out of the threatening material. A cathartic may insure the same protection, but should not be resorted to at all frequently.

It might be supposed that overeating would lead automatically to loss of appetite and so correct itself. But we cannot rely upon any such adjustment. A slightly excessive consumption of food may have no evident injurious effect for long periods of time, yet the ultimate result may be the shortening of active life through the early development of arteriosclerosis. It almost seems as though the subtle changes induced by such a small dietetic error were more serious than those likely to follow a more gross transgression.

Temperance in eating is doubtless the chief practice to be recommended as a safeguard against auto-intoxication and its evils. Temperance in drinking might be mentioned at the same time, for the moderate drinker is disposed to overeat and alcohol itself is a common cause of arteriosclerosis. It is more important to restrict the protein food than the other kinds, for the definitely poisonous compounds entering the blood from the colon are believed to be nitrogenous. Moderation in meat-eating is to be urged, but the reason, it

should be pointed out, lies in the peculiar attractiveness of meat rather than in its composition. Eggs, beans, and peas might have as much to do with auto-intoxication if they were as appealing to the average appetite.

It will be noted that we can avoid toxic decomposition in the intestine either by keeping the tract as free as possible from lagging residues or by controlling the prevalent type of bacterial action. This latter procedure has had many advocates. It is taught that the more harmful microorganisms can be kept from undue increase if less objectionable species are deliberately encouraged. This is the theory of the various sour-milk treatments. The familiar change that takes place in milk is a fermentation of milk-sugar with the formation of lactic acid. Although lactic acid in the muscular and nervous tissues of the body is clearly undesirable, it seems that a good deal of it may be introduced into the alimentary canal or produced there without ill effects. Certain kinds of bacteria which form lactic acid from sugars at a rapid rate can be isolated, grown in quantity, and dispensed.

The subject may prepare sour milk by means of these cultures and drink it, swallowing the acid and the producing organisms at once. Or he may prefer to swallow the cultures together with some sugar which may then be fermented within the tract. In proportion as this type of fermentation becomes the dominant one certain other decompositions are inhibited. It is a curious fact that something can be learned about the state of the colon by studying the urine. There are well-recognized products of protein putrefaction that may be absorbed into the circulation and later excreted in modified form by the kidneys. The amount of these compounds in the urine is thus an index of the extent of objectionable decomposition in the lower part of the canal. Lactic acid treatments often reduce the quantity of these tell-tale substances.

It has been suggested in Chapter XV that the human colon is, perhaps, as much a menace as a support to the individual. The idea that man would be better without it has been freely entertained. When it has been absolutely necessary to remove it and the immediate dangers of the operation have been passed, there has been no trouble in maintaining good nutrition. The discharges are watery and voluminous but contain little more than the normal food residues. In a few cases the colon has been removed, not because of local disease, but in the hope of bettering the general health through checking auto-intoxication. Occasionally the measure seems to be justified by the happy results obtained but surgeons do not recommend it unless the condition is quite grave.

Undereating.—Most of the popular writing on topics of this kind presses home the teaching that most people eat more than they should. There can be no doubt that overeating is common, especially among men, and most of all among those who have plenty of money. But we can hardly question that there are multitudes of people who are underfed. There are the very poor and there are those with more adequate incomes who still economize unwisely upon their food. Women are prone to make this mistake. They prefer to have money for so many other things that they do not allow themselves enough to eat. Often they are alone in their homes at noon and are too indifferent to make the exertion of getting a square meal. Appetite soon flags and a habit of undereating is established.

People who do not eat enough are likely to be underweight, pale, and sensitive to cold. They are often good workers but in their performance they are apt to appear conscientious rather than enthusiastic. They give an impression of having little energy to spare. They are apt to be light and fitful sleepers if not actual sufferers from insomnia. But the most evident effects of underfeeding are generally observed in the mental attitude.

These persons are depressed or morose, often querulous and prejudiced, seeming to be their own worst enemies. The contrast which they present with the overfed is a consistent one. The man who eats too much—and escapes indigestion—is usually overweight, florid, not very diligent, a heavy sleeper, and an optimist. There are drawbacks in either case. The picture of the underfed subject is much the same whether his habit is the result of outward circumstances or alimentary incapacity.

What happens when the ration is considerably reduced and held for a long time at the new level? In the midst of our war problems this is a timely question. It can be answered definitely. Those who are affected lose weight. After a time, if the cut has not been too drastic, they come into equilibrium again. They are now smaller individuals, and as such operate with greater economy both at work and at rest. If, however, they are now markedly underweight feelings of depression and inertia may be very troublesome. We can get along with less food by fulfilling any of these conditions: becoming lighter in weight, doing less work, keeping warm—not very practical suggestions in a national emergency! Our hope lies more in substitution than in reduction.

Food Poisoning.—We must indicate a distinction between auto-intoxication which is due to the production of poisons in the canal and the acute attacks which may be occasioned by food that has become poisonous before it is eaten. Such changes in food are fortunately rare. We need to reflect that very extensive decomposition may occur without making food dangerous. The supreme examples are furnished by certain cheeses which have been so treated as to advance putrefaction to the utmost. They rarely cause sickness.

From time to time we hear of outbreaks described as *ptomain* poisoning. They are undoubtedly less frequent than they were thirty years ago, for greater intelligence in regard to the control and inspection of food has had

a favorable effect. A ptomain is defined as a bacterial product derived from nitrogenous food. It is usually assumed to be rather simple in its chemical nature and has been described as an *animal alkaloid*. This is not a good term for we can probably obtain the same ptomains from vegetable proteins as from those of meat. The word ptomain need not of necessity suggest a poison, but it is usually so understood for, among many compounds released simultaneously in certain types of decomposition, there are some which are intensely toxic.

Meat and fish, including shellfish, have figured in most of the spectacular cases. A number of persons who have eaten food from a common source, it may be at a banquet, have become violently ill. A few hours after the meal they are seized with agonizing pangs, uncontrollable diarrhea, and, in most instances, forcible vomiting. The temperature rises to a fever pitch, there is extreme prostration, and death from exhaustion may occur. But the reaction of the system evidently favors a thorough removal of the poison and recovery is usually prompt.

There are odd cases of food poisoning which present an entirely different group of symptoms: a painless prostration, with more or less paralysis, and stupor. The poisons which produce such effects must be of a narcotic nature. The outlook is worse under these conditions than in the ordinary disturbance for it is most difficult to clear the sluggish and benumbed system of the agent that is threatening its life. Poisoning by decomposed mussels, molluscs eaten in Germany, has often had this narcotic character, and so has the sausage poisoning which has been recorded in the same country.

There is no apparent reason why other nitrogenous foods than meat should not undergo poisonous decomposition. In fact we have reports of sickness due to string beans which had been imperfectly preserved in glass. There is widespread objection to canned goods, but it does not appear that they have been responsible

for much acute poisoning. Neither does it seem that much damage has been done by metals and preservatives. Ice cream sometimes becomes excessively poisonous; it may be vomited almost instantly. Those who have studied poisonous ice cream most carefully do not believe that the metal from the freezer is concerned, but rather that it is a true bacterial alteration of the milk.

In times past, more or less illness has been caused by the consumption of meat from diseased animals. Unscrupulous men have hastily slaughtered and marketed animals which were about to die. (One is reminded of the permission conveyed in Deuteronomy, xiv, 21.) Such criminal acts are more effectively guarded against in these days. When we consider the possibility of damage being done by such meat we see that two distinct results may follow: the same disease that the animal had may be transmitted to man, or there may be a poisoning from the abnormal state of the tissues. Thorough cooking will protect against the infection, but it is not at all certain to neutralize the poisonous properties of the flesh.

We hear it said that "one man's meat is another man's poison." This is rather an extreme statement as related to the cases it is usually intended to cover, but it may be literally true. There are the most curious idiosyncrasies toward particular foods on the part of individuals. Some cannot eat eggs, others are made sick by lobster or crab meat. Certain persons are poisoned seriously by potato. Strawberries cause skin eruptions in many subjects. It has been surmised that some of these unfortunate reactions are due to suggestion, the painful memory of a past illness making a fresh trial with normal confidence out of the question. It is certain that some are of a more fundamental sort, the food producing its effect however perfectly it has been disguised.

Constipation.—Much is written of this condition. A great part of that which comes before the average reader is designed to promote the sale of cathartics.

It has to be discounted accordingly, and yet there is no doubt that constipation does much harm. Those who are most nearly immune to evil consequences are the small eaters. The "Fletcherite" who practises prolonged mastication and subsists on the lowest possible ration may have only one or two evacuations a week and still feel well and make a creditable showing when tested for mental and muscular capacity. He is saved from auto-intoxication by the small amount and dry character of the intestinal content.

The more liberal feeder is safer if he adheres to the time-honored rule of one movement a day. Regularity is not an absolute disproof of a constipated condition for there may be an undesirable lag in the progress of material along the canal. Not only should there be a daily unloading of the colon, but the feces should correspond with the intake of the previous day rather than of some day farther back. There is probably a great difference between the maximum and the minimum rate of travel along the individual intestines of a group of people who all consider themselves free from constipation. The slower the rate of advance the larger the amount of matter present at a given time to give rise to poisons.

It may even happen that a state of constipation shall have symptoms of diarrhea. There may be heavy accumulations in the colon which its contractions are too weak to displace and a catarrhal discharge from the irritated regions may create an entirely false impression. The advice of a good physician may be needed to determine what course shall be pursued.

The old-time doctor gave a powerful cathartic on almost every occasion. Many of the slight, nameless illnesses we suffer, especially in childhood, yield immediately to this measure. The quick return of normal feeling seems to favor the view that the trouble was an auto-intoxication and that the toxic matter has been adequately removed, but it is the part of wisdom

to limit the number of occasions for resorting to such means of relief. Most people can avoid recurrences by taking reasonable exercise, drinking a good deal of water, and eating fruit and coarse vegetables.

Washing out the colon now and then is a procedure which has its devotees. It has a real value in special cases, but is to be avoided unless prescribed by the physician. A dependence upon the enema may be established which is in the highest degree irksome and little better in principle than a cathartic habit. It may be said incidentally that one marked difference between the reaction to a purgative and an enema lies in the fact that the drug usually contracts the output of the kidneys by diverting water to the intestine, while the enema encourages the absorption of water and increases the volume of the urine. Irrigation of the colon is accordingly helpful when it is desired to promote elimination by the kidneys, as in some cases classed as rheumatism and arthritis.

Obesity.—Increase of adipose tissue can occur only when the income of the body is for some time in excess of the fuel requirement. This is a plain fact, but one which is not always recognized. It would seem to follow that such increases could be counteracted either by restricting the diet or by speeding up the oxidation. Both objects are often sought. If the food is limited the weight must diminish. When we are not eating or drinking we are necessarily losing weight at the rate of at least an ounce an hour. But fasting is not pleasant and insufficient feeding may be even more distressing.

The consumption of adipose tissue may be forced by exercise. A common difficulty is that the appetite is so stimulated that unless it is sternly curbed the accumulation is at once replaced. The victim has his labor for his pains. We have made a brief reference to the power of thyroid extracts to accelerate the metabolism and to the use of these preparations in medicines for weight reduction. They are not ideal for the purpose since

they produce nervousness and disturbances of the heart action.

The choice of a diet containing an unusual quantity of protein has been recommended for the purpose of cutting down the weight. The old theory was that protein could make muscle but not fat, an idea favored by the leanness of carnivorous animals. We have been brought to believe that fat *can* be made from protein, with sugar as an intermediate stage. The effect of a high protein diet can be explained as due to two factors. In the first place, it is likely to be satiating and the amount eaten is automatically reduced without any suffering from hunger and faintness. In the second place, protein, more than other types of food, stimulates the rate of oxidation. The technical expression is that "it has a marked specific dynamic effect."

One system of treating obesity depends on the rather heroic principle of giving drugs which keep the patient in a qualmish condition and abolish his appetite. Fasting is thus made easy, but it does not seem as though the after-effect upon the organs of digestion could be good. One might choose to be fat rather than dyspeptic.

The great trouble with most of the methods employed to reduce weight is that the constitutional tendency is unaltered by them and results are apt to be temporary. The subject faithfully follows a routine at the cost of much self-sacrifice and rapidly regains the loathed adipose tissue when he changes his mode of life. Perhaps the most practical suggestion for a line of conduct that can be kept up indefinitely is that bulk rather than nutriment be sought after. The clamors of the stomach can be stilled by filling it with fruit, green vegetables, pop corn, etc., instead of with bread and butter, potato, pastry, and candy. It is a policy of self-deception but warranted in a good cause.

The Teeth.—Digestion and nutrition depend to a considerable degree upon mastication. It is probable that too much virtue has been claimed for the chewing

of the food, but it is certainly better to err in the direction of excessive rumination than to become careless in regard to it. The teeth are to be conserved and used. It might be thought that the vigorous employment of the teeth could only hasten their wear and tear. This is probably the case at a time when their life is extinct or limited to a small central core, but at an earlier period mastication appears to be good for the teeth. This is because they are made to sink and rise in their sockets with a massaging effect upon the gums and some promotion of the circulation in the pulps.

According to the usual teaching the best protection to the teeth is afforded by the use of an alkaline mouth wash such as milk of magnesia. If this is used at bedtime it should not be rinsed out but left in the by-places of the mouth to guard against the development of an acid reaction. The brushing of the teeth may be overdone; it should cleanse their surfaces but should not be so directed as to encourage recession of the gums. It is often assumed that people with poor teeth are paying the penalty for their neglect. Sometimes, of course, this is a fact, but it is also true that many people have superb teeth which they owe entirely to good fortune and not to conscientious care.

The assistance of the dentist must be had at short intervals by many subjects. Teeth which are in need of filling or other treatment are most detrimental. They are not merely disfiguring and responsible for bad breath, but their presence deters the possessor from using proper force in mastication. It is believed in addition that defective teeth are often foci from which most injurious infections are spread to other parts of the system. The ugly fact stands out that our teeth, being incapable of self-repair, force upon us an early reminder of our mortality.

CHAPTER XXVII

THE MAINTENANCE OF THE BODY TEMPERATURE

One of the most impressive examples of coördination is afforded by the associated mechanisms which so successfully preserve the human body temperature from violation. Summer and winter, indoors and out, in the polar regions and in the Sahara, it seems independent of external conditions. A discussion of the facts has been postponed to this time because almost all the other divisions of our science are needed as a foundation. The manner of working of the nervous system with its receptors and effectors, the nature of the contractile process in skeletal muscle, the government of the circulation, and the factors in metabolism must all be in mind.

Most animals do not have this wonderful ability to hold themselves to a constant temperature. Birds and mammals generally possess the power and we indicate it when we call them warm-blooded. Speaking accurately, we do not mean so much to emphasize their warmth as the *constancy* of their internal state. If a fish and a duck are both swimming in water having a temperature of 103°F., the two may have the same internal temperature. But if the water cools down the fish will passively submit to a parallel cooling while the duck will be about as warm as before, so far as its deeper tissues are concerned. When we call the fish a cold-blooded animal we mean that it takes very nearly the temperature of its surroundings.

In the interest of precision we may substitute for warm-blooded the word *homothermous*, which means having a uniform temperature. The standards so strictly

adhered to by birds and mammals are in the same general region, say between 97° and 110° . The highest temperatures are those of small birds. It was suggested in Chapter XVI that the salts of the plasma are reminiscent of those in the pre-historic sea from which ancestral forms of life came to land. It may also be suggested that the temperatures so faithfully perpetuated by birds and mammals of the present are those which were impressed upon the early organisms by the water in which they lived. It may be argued that if this is so the cold-blooded animals are really the ones which have more perfectly met the geological conditions of our time. The failure of the homothermous to adjust themselves obliges them to metabolize a great deal more food than would be necessary if they took the temperatures of their environment. The low temperature of fishes does not prevent them from being very active; on the other hand, we do not find much cerebral capacity in any of the cold-blooded species.

When we speak of constant temperatures we have always in mind the internal and not the surface conditions. The temperature of the human skin cannot be constant since it is influenced by the varying state of the air as well as by the changes in the circulation. The skin temperature approaches that of the blood most nearly when the vessels are locally dilated and when a covering retards the loss of heat to the air. We know that an exposed spot is not proof against frost-bite which shows how the regulating mechanism may be overmatched.

The clinical thermometer may be used in the mouth, the armpit, or the rectum. Occasionally other localities are utilized or the temperature of the urine may be taken. If the mouth and rectal temperatures are taken at the same time the latter will generally be the higher by about half a degree. The difference is increased when there is deep breathing because of the cooling effect on the whole region about the mouth. Runners who are

panting from long exertion may show an elevation of the rectal temperature but no corresponding rise in the mouth.

There is a slight daily rise and fall of the temperature wherever measured. The lowest point is passed in the early morning before the reluctant muscles have been roused to much activity. There is an upward tendency through the day and the highest level is reached late in the afternoon or early in the evening. The extent of the fluctuation is rather more than 1°F . When there is fever the same ascending curve is usually recorded and the patient is likely to be more restless and uncomfortable toward night.

While we recognize the daily variation it is still plain that the approximate constancy of the body temperature is the outstanding fact. Where heat-production is always going on uniformity of temperature must be due to a balance between this production and the concurrent loss, between *thermogenesis* and *thermotaxis*, if we adopt the language of science. The place and manner of heat-production are already familiar; it occurs chiefly in the skeletal muscles with supplementary contributions from the heart and the glands. We have now to add some details regarding heat loss.

The total for the day is that of the metabolism; we will again assume 2500 Calories. We know that some of this heat is imparted to the air and the surroundings in general. Another fraction of it becomes latent through the evaporation of water. The relative amount of the two portions will depend on the external temperature. If this is low, as in winter, the subject will evaporate much less water than if it is high. A water loss from the breathing passages and the skin aggregating 1000 grams will render latent over 500 Calories, as previously stated. The remaining Calories of our assumed total—about 2000—will, in this case, be directly measurable as heat given to the surroundings.

A proportion like that just suggested may be ex-

pected with a moderate external temperature. If the chamber is made warmer the share represented by evaporation will be progressively increased until, with an outside temperature equal to that of the body, *all* the heat produced must be made latent by evaporation. To get rid of the whole 2500 Calories in twenty-four hours, a man in a chamber at 99°F. would be compelled to secrete through the respiratory tract and the sweat glands nearly 5 liters (more than a gallon) of water. He could not add measurable heat to his environment—that is, he could not make it warmer—when it was at his own temperature in the first place.

A man subjected to this severe trial would not give off extra water to any extent by increasing his breathing, but almost wholly by increasing his secretion of sweat. Animals like the dog which pant when they are in a warm atmosphere rid themselves of surplus heat almost entirely by increasing evaporation from the mouth and throat and the extended tongue. We are not to assume that their behavior indicates any such distress as it would in the human subject.

As the skin is warmed the receptors which lie just under its surface are stimulated. The reflexes which result are both vasomotor and secretory. The vessels of the skin are dilated and a larger share of the total blood-stream than usual finds its way through them. This favors the cooling of the blood unless the external temperature is equal to or above the internal. With the ordinary balance reversed the cutaneous dilation would cease to be a protective reaction if it did not help to sustain the sweat glands in their augmented activity.

Humidity.—The possibility of evaporating water depends on the extent to which the air is already saturated—in other words, on the humidity. If the air in contact with the skin holds all the water which it can, we cannot expect it to take more save under one important condition: *it may be warmed and gain in its*

capacity to contain water vapor. We have said that this happens when air fully saturated, but cooler than the tissues, is respired. It happens also when such air blows over the surface of the body. High humidity is, accordingly, not a serious obstacle to evaporation from the skin unless the air is exceptionally warm.

The coincidence of high temperature with high humidity is uncomfortable and even dangerous. We know that the most trying days of the summer are not, as a rule, the ones on which the highest records are made by the thermometer; they are rather the days which we characterize as sticky and lifeless. Loss of heat from the body is impeded by the limitation of evaporation as well as by the actual warmth of the surroundings. It has been found that men working in deep mines where it is both warm and moist may have continuous fever temperatures. Their situation is almost intolerable. The miner may be in a much worse position than the stoker of the steamer who endures a much hotter atmosphere.

The air that is brought into the fireroom of the steamer is fresh from the cool exterior and when it is heated it comes to have a very low relative humidity. It is well adapted to take up the water which is secreted in such abundance by the toilers. We must call attention to the fact that we cannot judge the amount of the perspiration by the appearance of the skin. So long as evaporation fully keeps pace with the production there may be no visible moisture. It is when evaporation lags behind the outpouring that we notice the drops. We are actually most conscious of the perspiration when it is failing to accomplish its purpose. An English student of these problems has asserted that a man cannot work with safety in fully saturated air at 90°F., but can be protected by *warming* the same air by 40°. The paradox is easily explained. Heating the air gives it a low relative humidity and the evaporation which was very slight at 90° becomes extremely rapid at 130°. Fortunately for our comfort and safety the humidity normally falls on any hot

day as the temperature rises. Take, for example, the records of August 7, 1918, the warmest day known in New York:

	Temperature, degrees.	Humidity, per cent.
8 A. M.	86	63
10 A. M.	93	54
12 M.	97	42
2 P. M.	99	39
4 P. M.	102	35
6 P. M.	99	38
8 P. M.	96	50
10 P. M.	92	72

The last combination was probably the hardest to bear.

Individuals have endured incredibly high temperatures when the conditions have been favorable to free evaporation. In the eighteenth century a series of trials was made by three members of the Royal Society of London and they finally achieved the distinction of having remained for a quarter of an hour in an atmosphere at 225°. Water boils at 212°. Their feet were protected by thick straw sandals and it is recorded that one of them blistered his hand by touching his watch chain. A piece of meat was cooked during the experiment by simply exposing it on a plate. The survival of these men and others in similar cases must be due to the presence close to all the surfaces of the body, including the respiratory tract, of a layer of relatively cool air.

Radiation and Conduction.—Heat which escapes from the body to warm the surroundings is transmitted in two ways. A part of it is *conducted*. By this we mean that it raises the temperature of matter in direct contact with the body and then that of more matter just beyond the first. Heat is conducted from a man's body to the bricks of the cold wall against which he leans. It is conducted to the cold water through which he swims. Some substances are superior conductors of heat and these feel cooler than others of the same temperature. Iron feels colder than wood because it receives heat from the skin at a more rapid rate, the temperatures of the iron and the wood being equal.

By *radiation* we mean the very swift departure of heat through space. We radiate heat through the air without heating the air itself to any appreciable extent. Heat may pass from the human body across a room to be absorbed by the frosty window panes. Outdoors it may go into interminable space. The heat which we radiate is often compensated by the heat radiated to us. Two rooms may have the same temperature as determined by thermometers hanging in central locations, but one may seem much cooler than the other if it has cool walls and windows. In this room we radiate heat which



FIG. 77.—Cats in hot and cold environments. (See text.)

is not returned; in the other the give and take are more nearly equal.

Radiation is hindered by humidity. All things cool down more rapidly at nightfall if the sky is cloudless and the air dry than when it is foggy. It is in regions of low humidity, like Arizona, that the greatest differences between night and day occur. But the humidity that limits radiation favors conduction and this gives cold, damp air an added chill. Winter on our Atlantic

coast is declared to be more trying than the same season inland although the thermometer goes much lower in the interior. For the same reason that water feels colder than air of the same temperature moist air feels colder than dry. High humidity makes us warmer in summer and colder in winter.

In discussing the conditions affecting the metabolism we have shown how the body meets external cold. The skeletal muscles are called into extra activity. Without special coverings to keep the heat pent in the body one cannot be still. A rise in the metabolism is secured which is, as we have insisted, essentially a case of exercise. We have saved ourselves to a great extent from the need of such an increase by adapting our clothing to the weather. Animals do the same thing by posture. On a hot summer day a cat may be found stretched at full length with the tail extended and the paws well apart. In this position the fur along the ventral surface is opened to the air.

On a cold day the cat squats with its paws pressed against the body, the tail laid alongside, and the ventral aspect covered in from the air. The surface exposure cannot be one-half of what it is in the extended attitude. Rabbits generally keep the squatting position and its value is shown by the fact that they readily succumb to cold when they are prevented from doing so. This is the more striking because rabbits endure the most severe climates.

Temperature Regulation during Exercise.—We have considered thus far the problem of temperature maintenance with varying outward conditions. We have found that within wide limits this is a matter of restricting or facilitating the loss of heat from the body rather than a regulation of the rate of heat production. When a man who has been resting rises and sets out on a brisk walk we have a distinct case to analyze. External factors may be unchanged but the metabolism is much increased. If the body is to be successful in avoiding a

fever it must make adjustments to dissipate the extra Calories which it is generating.

Two factors are recognized which are operative both in the adaptation to warm surroundings and to muscular activity. These are the dilation of the cutaneous vessels and the secretion of sweat. But we must note a difference between the skin which is flushed by contact with warm air and that which glows with exercise. In the former the blood is not moving at an unusual rate through the dilated vessels; in the latter the velocity is presumably increased somewhat with the general quickening of the circulation.

Two other factors are discovered during muscular activity which are not clearly present during simple exposure to warm air. One of these is deep breathing. It is only certain species of animals which pant when they are warmed from without but all animals breathe deeply when they are producing uncommon quantities of heat internally. The primary service of the increased ventilation of the lungs is to provide more oxygen and remove more carbon dioxide but the discharge of heat is promoted at the same time.

Another means of shaking off heat during exercise is found in the constant shifting of contact between the skin and the air. The effect is that of a breeze. It is plain that a man who is riding a bicycle, running, or walking enjoys this favoring condition. The same is true in a measure of the man who is standing in one spot and swinging his arms; he profits by the fanning of his skin. The air which lies against it at one moment and has become warm and moist is replaced a moment later by cooler and drier air. An important detail is the pumping of air from within the clothing and the substitution of fresh portions. When one is resting, the air in contact with the skin and under the clothing is warm and nearly saturated. Someone has said that "with the exception of head and hands we live in a tropical climate."

Fever.—The body temperature will rise above the

standard if heat production is increased without a compensating increase in heat loss. It will also rise with a uniform heat production if heat loss is interfered with. The fever of the Cornish miners, to which we have referred, illustrates more particularly the second difficulty. The metabolism was not too high to be offset by thermotaxis if the external conditions had been reasonable. The combination of high temperature with high humidity led to an accumulation of heat in the tissues.

It may be said of fever in general that it is not so much the result of high metabolism as of a failure of the mechanisms of heat dissipation. It is true that the heat production of the restless patient with his rapid heart and breathing is higher than it would be if he were well and lying comfortably in bed. But it is by no means so high as it might be if he were well and taking exercise. The best statement that we can make regarding fever is that the trouble is with the nerve centers through which the balance between thermogenesis and thermotaxis is normally maintained. When a fever is holding a steady course the balance *is*, in fact, preserved as delicately as in health. It is the false standard to which the system is held which is the real characteristic.

It will be well to point out here something which may have been gathered from statements made earlier in the book. This is the fact that our sensations are altogether unreliable as indicators of the body temperature. They are entirely dependent upon the skin. If the surface of the body is warm we say that *we* are warm. The glow produced by alcohol furnishes this impression, but what is actually sensed on such occasions is the flux of heat from within the body to the exterior. The subject feels warm because heat is escaping through his skin. Sub-normal temperatures have often been recorded when the influence of alcohol has been coupled with exposure to cold.

Conversely, when the circulation in the skin is abnormally reduced the feeling is likely to be one of chilliness, but

the restriction of heat loss at such a time may lead to a rise of the internal or true body temperature. In the chills of malaria this is just what happens. The patient can scarcely be made to feel comfortably warm because of the severe constriction of the vessels of the skin. The surface cooling leads to reflex shivering and the muscles produce extra heat which is retained in the internal organs. The temperature mounts high above the normal while the sufferer appeals for more covering. Later, the skin becomes flushed and the sensation is one of rising temperature, though the fact is that the system is parting with its stored heat and returning to the normal state.

CHAPTER XXVIII

INTERNAL SECRETIONS

When we think of the means by which coördination is secured in the body the picture of the nervous system at once rises before us. It is true that the quick adaptive reactions by which emergencies are met proceed from the flight of nerve-impulses. But it is a fact much better appreciated now than a few years ago that chemical compounds borne from place to place by the blood have a great deal to do with internal adjustments. The subject may be called that of the internal secretions or, using a term we have already employed, the *hormones*.

A hormone is a substance produced in a definite locality but having its effect elsewhere, perhaps at a great distance. At least two examples which have been mentioned should be recalled. One is the *secretin* formed in the lining of the duodenum and taking effect upon the pancreas and other digestive glands. A different hormone, *gastric secretin*, is believed to arise in the lining of the stomach under the influence of secretagogues and to be the chief cause of the late formation of gastric juice in the normal period of digestion.

Another internal secretion of which it was necessary to speak in an earlier chapter is that contributed by the pancreas to the circulation and essential to the oxidation of sugar. The want of this hormone is responsible for diabetes. We must now add to these examples several others. It may be said at the outset that a greater degree of confusion exists in this department of physiology than in any other. This is partly owing to the newness of the recognition of hormones but is partly inherent in the subject itself. Fresh discoveries are being reported and

still more are to be anticipated. But down to the present time the observations have constantly increased the difficulty of the whole matter.

It may fairly be claimed that every kind of tissue may give rise to hormones. That is, it may be argued that the tissues differ in their chemical nature and metabolism so distinctly that each one must have products which no other can evolve. The normal composition of the blood must depend on the blending of all these innumerable contributions. It is curious to reflect that the Greek masters in medical science taught that health was founded on the right combination of chemical principles, the "four humors," in the body. We are coming to believe in our own age that many disturbances of health are actually due to excesses or deficiencies of internal secretions, a view that obviously recalls the ancient one. While the formation of hormones may be theoretically universal, there are some organs which exhibit it most conspicuously and of these we have now to give brief accounts.

The Thyroid.—The thyroid gland, or thyroid body, is in the neck between the larynx above and the breast bone below. There are two lobes united by an isthmus which crosses in front of the trachea. The normal thyroid is small and not easily noticeable from the surface, but there are many thin subjects in whom its form is quite apparent. It may be greatly enlarged and when this is so it forms the disfiguring swelling known as a *goiter*. The enlargement may not be attended by other than local symptoms, but in many cases it is the central element in a serious disease.

We have said that extracts of the thyroid produce nervousness, emaciation, and palpitation of the heart when given to human subjects. The enlarged gland may deal out to the circulation abnormal quantities of an internal secretion capable of just these effects. The result is much as though the extracts were given by the mouth. In bad cases an odd symptom is a bulging of the eyes.

As there may be too much of the thyroid product, so there may in other individuals be too little. The effects are consistent with those that have been described. Instead of nervousness there is apathy and dullness; instead of emaciation there is corpulence. A peculiar characteristic of the person with insufficient thyroid is the overgrowth of the connective tissue beneath the skin. This destroys the grace of all the contours and particularly affects the features, making them heavy and uncouth. The disease is called *myxedema*.

The symptoms we have just referred to are those shown by a person who has formerly had a normal thyroid but has lost its support more or less completely. Another possibility is that the thyroid may be inactive from birth. This has a shocking consequence: the child remains in a state of arrested development both physically and mentally. It is said to be a *cretin*. It is not only dwarfed but ill-proportioned, having a heavy head and abdomen and weak muscles. The development of a cretin can be greatly assisted by adding to its food at an early period some of the dried substance of the thyroids of animals. The impulse given to growth and the approximation to a normal type under the influence of thyroid feeding are among the most wonderful demonstrations of modern medicine.

The main mass of the thyroid is composed of a tissue which suggests that of a gland, such as the pancreas, but with an important difference. The cells are observed to surround recesses, as in the true gland, and the recesses seem to be distended with a secretion, but there are no ducts. Any active product must leave the seat of its formation by the lymph or the blood. The force of the term internal secretion comes home to one while



FIG. 78.—The thyroid in its relation to the trachea.

looking at such an arrangement. Four small nodules of a distinctive tissue, unlike that of the main thyroid, are found imbedded in it or close by. These kernels are the *parathyroids*, and there is no doubt that they send out a valuable hormone. In their absence convulsive disturbances of the skeletal muscles occur.

The Adrenals.—These are two small bodies which are placed above the kidneys. The fact that they are necessary to life has long been known. If they are wasted by disease, as by a localized tuberculosis, one or more indispensable hormones seem to be lost. The victim grows

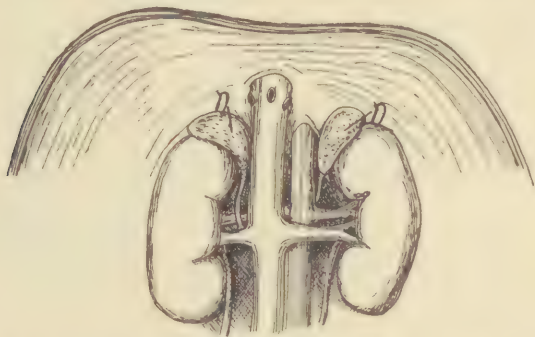


FIG. 79. The adrenals (*n,n*), surmounting the kidneys and close under the diaphragm.

weak, suffers from incessant nausea, and dies as though from exhaustion. An incident of the decline is a dark pigmentation of the skin which has given the derangement the name of *Addison's bronze disease*. Dogs deprived of the adrenals soon die.

An extract of the adrenal body has extremely active properties, but it has not found its chief use in the correction of Addison's disease, as might be inferred from the account of the thyroid. The adrenal extract is sold under the name of *adrenalin*. It contains a substance which can be isolated and which is responsible for most of the powers of the extract; it is called *adrenin* or *epi-*

nephrin. It is applied to wounds to check bleeding, for one of its effects is to cause an intense contraction of small blood-vessels. This has made adrenalin valuable to surgeons for work on the eye, nose, and throat.

It has lately become probable that we must distinguish between two functions exercised by the adrenal bodies: they have an obscure relation to the continued welfare of the system as a whole and, in addition, an occasional or *emergency function*. This is performed under excitement. In Chapter XII we made the point that emotion is a form of exercise and accompanied by an extensive discharge of impulses along various nerves. It has been shown that among these streams of impulses there are some which reach and arouse to unusual activity the adrenal bodies. It will be well to describe an experiment which has given proof of this effect.

Very delicate tests for the presence of adrenin in fluids have been made available. One of these tests may be applied to a sample of blood taken painlessly from the veins of a cat, and there will usually be no sign that adrenin is present. If the test is repeated after the cat has been excited by seeing a dog the secretion will have made its appearance. We conclude that one feature of the emotional crisis was a rapid discharge from the adrenal bodies of a hormone which they ordinarily supply only in minute quantities. When this discovery was made it was natural to inquire whether the adrenin could serve any useful purpose. The question has been answered in the affirmative.

It has been found that the contraction of the blood-vessels which occurs under the influence of adrenin is not uniformly distributed. Some areas are affected more than others. The most marked constriction takes place in the abdominal viscera. Meanwhile the vessels of the lungs, the heart's walls, and the skeletal muscles are not contracted at all. There will be no interference with the pulmonary circulation and a positive promotion of blood-flow through the muscles. A great master of

physiology has interpreted the reaction for us from the point of view of its value to the individual.

An emotional occasion is an occasion for action. This was universally true under primitive conditions of life among men and it is true in the lives of the lower animals. Fear is the prelude to flight. Anger is the impulse to attack. Under the experience of pain there are efforts to escape from the cause of suffering where this is possible. There is need for the fullest command of all bodily resources in these crucial exigencies. It can be demonstrated that adrenin helps to realize such a command.

Take first the effect upon the distribution of the blood noted above. It is clearly favorable to the maximum activity of the muscles. The progress of digestion and the other processes which may be going on in the abdominal organs can be held in abeyance for the time being. The most vital needs are given the precedence. At the same time there is likely to be some rise of arterial pressure and this accelerates the circulation through the muscles. Until the actual struggle is under way the skin may be pale rather than flushed; this indicates the greatest possible concentration of the blood-flow in the vessels of the motor organs.

Another service of adrenin is known to be a postponement of fatigue. A very small addition of the adrenal principle to the blood of an animal whose strength is flagging may give a renewed command of the muscles. The gain is partly in the way of better end-plate transmission, but probably there are other points of application. It is now believed that the secret of "the strength of desperation" is largely in the timely discharge of adrenin into the blood-stream.

Still another result of the emotional disturbance is a rapid transformation of the liver glycogen into sugar which at once enters the blood. In Chapter XXIII it has been stated that the resulting hyperglycemia may be so marked as to cause the appearance of sugar in the urine. The loss of the carbohydrate cannot be of any

use, but the temporary concentration of the sugar in the blood may be purposeful. The wise interpreter whose exposition we are following points out that extra fuel of the preferred kind is thus offered to the muscles. So they are made unusually responsive to stimulation through their nerves at the same time that they are provided with a liberal allowance of sugar for oxidation.

An odd alteration in the blood which can be noted directly after excitement is a shortening of the time required for coagulation. The reduction is very marked. The suggestion is that an exciting situation is one which may be followed by conflict and loss of blood. The chances of victory and survival will be better for the combatant whose blood most promptly staunches its own flow.

Adrenin plays a part in securing all the valuable adaptive changes that have been enumerated. It would not be wholly correct to say that it can, without assistance, cause them all, for its influence is intimately combined with others of a nervous order. There are certain nerve paths in the body which can be stimulated with the result that the following effects are produced: quickening of the heart, dilation of the pupils, contraction of the abdominal blood-vessels, erection of the hairs, sweating, and the discharge of adrenin. Adrenin itself can produce most of the associated reactions. It may be conceived that during the experience of emotion impulses from the brain traverse these paths, adrenin is added to the blood, and the hormone perpetuates and extends effects which were at first nervous in origin.

It may be remarked that although these bodily changes are admirably suited to the needs of animals and cave men, they are not so well suited to the restrained life of civilization. When we experience emotion we try to refrain from manifesting it violently. It is not unlikely that the physical accompaniments are harmful when no application of them is made. Yet, as was said in Chapter XII, a life deficient in emotion is a life lacking

important elements of training as well as of interest. The conclusion is that emotion should not be excluded, even though that were possible, but that it should be given reasonable expression—made a motive for action. When we work off our anger or express our happiness in deeds we are true to our remote biologic inheritance.

Other Organs of Internal Secretion.—One of these which has claimed a good deal of attention recently is the *hypophysis*. This is a small but compound structure united by a stalk to the under surface of the brain. It is lodged in a hollow of the sphenoid bone. The removal of an organ so situated requires a severe operation, but it has been accomplished many times. The loss of the entire hypophysis is fatal after a short interval. There is reason to think that it is a producer of hormones. When it is diseased development is perverted, the resulting abnormalities being mainly in the shape of the bones.

When one looks at the pictures which have been made of persons with disease of the hypophysis or the thyroid one is inclined to think that a great many individuals show in slight degree the departures from the normal which are carried to an extreme in these selected cases. We constantly see faces which are strangely moulded and which do not seem to register the true character and intelligence of the man or woman. The underlying condition may well be an excess or a lack of some internal secretion.

The Reproductive Glands.—We have seen that the same organ may send products to the exterior and to the circulation. This is true of the pancreas. While it prepares a valuable digestive juice it is also making a contribution to the blood. We find a corresponding state of things to hold for the testes and the ovaries. The unique function of these organs is to detach the germ-cells which shall originate a new generation, but they are not without influence upon the organisms which bear them.

Removal of the reproductive glands from young animals profoundly modifies the course of their de-

velopment. Sterility is only one result among many. The contrast between the ox and the bull, the stallion and the gelding is a familiar one. It is as much a contrast in temperament as in build. Animals without the generative organs are said to lose, or rather never to acquire, the *secondary sexual characters*. In man these include the beard and the large larynx which accounts for the average difference of an octave in the pitch of male and female voices. After maturity has been attained the changes that follow the operation are not striking.

One of the marks of a male frog is a bulbous thumb. It has been found that the early removal of the testes prevents the development of this character and that it is formed within a short time after the grafting into the body of a testis from another frog. There could hardly be a clearer demonstration of the power of hormones liberated by one tissue to influence the metabolism of another. If the transmitted effect were a nervous one it would make a difference where the grafting had been done; in fact, it makes no difference at all.

Some years ago it was argued that the decline of the reproductive system in advanced life might have much to do with the simultaneous deterioration of other organs, especially the brain and cord. Vigor and efficiency might be prolonged, it was thought, by introducing into the body extracts from the reproductive glands of animals. Trials were made upon senile subjects, who reported some stimulation. But the results fell far short of the rejuvenation that had been hoped for and such as were described have been credited for the most part to suggestion. There has been no widely approved use of the testicular extracts since the failure of the so-called Elixir of Life. Ovarian extracts have been employed with advantage to abate distressing symptoms which follow the removal of the female organs.

The Spleen.—This large organ is of a type which might lead to the expectation that it could be shown to have an internal secretion. The evidence, however, has not

definitely supported the natural assumption. The spleen has a large blood-supply and is periodically contracted and enlarged as though it were actively engaged in some way. But it has been found that animals and men survive its removal, provided they rally from the immediate effects of the operation. Obscure differences in the composition of the blood have been noted in such surviving animals, and we have previously said that there is sometimes a lessened destruction of the red corpuscles.

The Thymus.—This is an organ below the thyroid and behind the upper part of the breast bone. It is very large in embryonic life and through infancy, gradually diminishing later until only scattered remnants of its tissue are left. It is the “neck sweetbread” of the market. It is probable that the thymus has some regulating effect in the processes of growth and development. The same has been claimed for the *pineal body*, an outgrowth from the dorsal surface of the brain-stem.

Attention has been called recently to the similarity between the effects produced by feeding the substance of several organs of internal secretion and the influence of the bodies we have called vitamins. The hormones from the thyroid, the thymus, the hypophysis, and the pineal body may enter into the nutrition of various tissues in much the same helpful way as these accessory compounds in the diet. The suggestion has also been made that the vitamins are particularly useful to the glands of internal secretion. These organs may transform the vitamins of the food into hormones needed by the tissues.

There is an aspect of this subject which, in the present state of our knowledge, adds greatly to its difficulty and obscurity. This is the circumstance that the organs of internal secretion have reciprocal relations of extreme complexity. One hormone may be auxiliary to another or it may be antagonistic. The future treatment of the matter will be shaped in conformity with a vast number of facts of this kind and its trend can hardly be foreseen.

CHAPTER XXIX

REPRODUCTION

IT is our purpose here to extend the account of the reproductive process briefly outlined in Chapter III. In the previous presentation it was stated that the body of any one of the higher animals, including man, has grown from a single cell, the *fertilized ovum*, by countless cleavages. The statement has also been made that the fertilized ovum is best viewed as a combination of two half-cells, the fusion of which is the starting-point of the development of a new generation. These two half-cells are contributed by the two parents. The male is said to furnish the *sperm* (or *spermatozoön*), and the union of this element with the unfertilized ovum of the female is described as *fertilization*, *impregnation*, or *conception*.

The reproductive cells (for so we usually call them, though we have said that they are more truly half-cells) are detached from the *gonads* or reproductive glands in the two sexes. These are the *ovaries* in the female and the *testes* in the male. The ovaries of woman are small solid masses of tissue, situated at the base of the abdominal cavity, one on each side. The ova are gradually matured in the ovaries, and from time to time released from the surface of these organs. The number of the perfected ova provided is not great, perhaps 300 to 400 in a lifetime. This is about the number of the menstrual periods, and it is roughly true that the production of ova begins and ends with the menstrual phenomenon; that is to say, it begins at about fifteen and is ended at about forty-five years of age. But it is not certain that there is a close coincidence between a particular menstrual period and the liberation of an ovum.

It is a singular fact that the ova are shed into the body

cavity. One would say, from a superficial study of the anatomy of the parts, that there was no certainty that an ovum would follow a definite course toward the exterior. But such a course does appear to be followed save in rare cases. Near each ovary is the expanded end of a slender passage, the Fallopian tube. These two passages converge upon the uterus, the hollow organ provided for the devel-

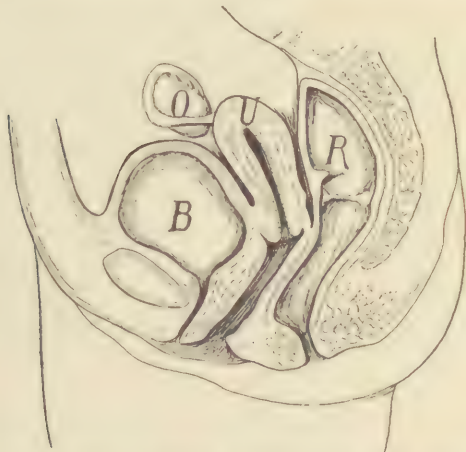


FIG. 80.—The female genitalia exposed by a mid-section. *B* is the bladder, *U* the uterus, *R* the rectum, and *O* the right ovary, which is to be thought of as beyond the plane of the section. The branched extremity of the right Fallopian tube is resting on the ovary.

opment of the embryo. When it is not the seat of this process the uterus is a small pear-shaped sac with comparatively thick walls and a limited cavity. It is placed between the bladder in front and the rectum behind. Communication between the uterus and the outside is afforded by the *vagina*, a passage with corrugated walls which admit of great distention. Through the vagina the great majority of the unfertilized ova are assumed to make their escape.

The gonads of the male, the testes, originally occupy a

position in the body more or less comparable with that of the ovaries in the female, but about the time of birth they descend into a double pouch, the *scrotum*, suspended from the *perineum* ("crotch"). From the period of sexual maturity onward to old age they produce spermatozoa in prodigious numbers. These find their way through coiled

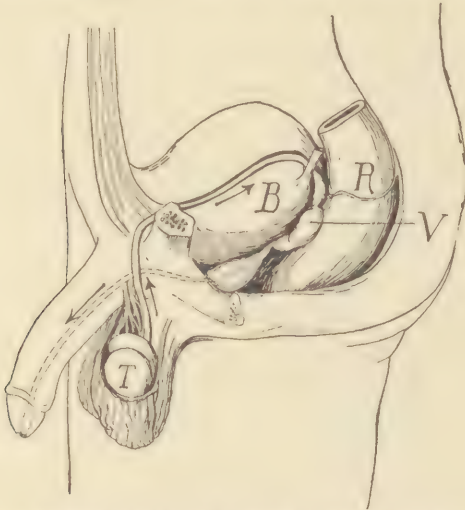


FIG. 81.—A diagram of the male genitalia. The section is somewhat to the left of the mid-plane. *T* is the left testis. The spermatozoa are conveyed along the course indicated by the arrows. So they reach the (left) seminal vesicle *V* at the base of the bladder *B*. The channel provided for their discharge, the urethra, is dotted. *R* is the rectum.

passages of minute diameter and incredible length to a pair of contractile containers, the *seminal vesicles*, on the under surface of the bladder. During the height of sexual excitement the seminal vesicles are thrown into rhythmic contractions and the spermatozoa, borne in a complex secretion, are forced out by way of the *urethra*, the channel ordinarily serving to discharge the urine.

The male urethra extends the length of the *penis*. This organ is described as *intromittent* in function; that is, when

rendered firm by engorgement with blood it is adapted to be thrust into the vagina and so to convey the seminal fluid to the very portal of the uterus. This constitutes the act of *coitus*. Excitement is obviously necessary in the male; it is not necessary, though normal, in the female.

The ovum is a microscopic sphere answering well to our idea of a typical cell. It has no inherent power to move, but is transmitted by currents of ciliary or other origin. The spermatozoa, on the contrary, are highly active swimming elements. Each one has an oval "head-piece," a minute "middle-piece," and a lashing tail or flagellum by which it is propelled. Its progress suggests that of a tadpole. When a host of these motile cells are set free high up in the vagina the chances favor the entrance of some of them into the uterus and a smaller number may even reach the Fallopian tubes. In one of these passages the fertilization of an ovum may then be accomplished.

The seemingly prodigal production of spermatozoa of course increases the chance that this will occur. Only one sperm can take part in the actual impregnation. Among lower forms of life, such as star-fishes, we can watch the entrance of the sperm into the ovum. As the boundary is passed the tail, now superfluous, may be detached and left outside. A prompt chemical alteration in the egg must be inferred to take place, for it seems at once to be protected against the intrusion of other spermatozoa, which are likely enough to blunder against it. We have every reason to believe that the facts correspond for the higher types which do not admit of such direct observation. In many cases thick envelopes surround the ova and superfluous sperm-cells often stop in these external zones.

We have said that a cell usually contains a nucleus as a conspicuous feature of its organization. The infertile ovum has such a nucleus surrounded by a relatively large volume of cytoplasm. The sperm also has a nucleus—we may almost say that it *is* a nucleus, for it has little other substance. The central fact in fertilization appears to be

the fusion within the egg of the nuclear material from the two parents.

A child inherits equally from the father and the mother. This recognized fact may prove puzzling to the student, who will be disposed to say that the paternal contribution is infinitesimal compared with that derived from the mother. Biologists have been led to the belief that the inherited traits, as these are commonly recognized, must be associated with the nuclei of the germ-cells. The nuclear material, as we can plainly see, comes equally from both



FIG. 82.—1, A spermatozoon or male germ-cell highly magnified. 2, An ovum less highly magnified. It has a rather conspicuous envelope, the *zona pellucida*. 3, An ovum which has been exposed to the sperm. *s*, The half-nucleus derived from the head of a spermatozoon which has entered the interior of the egg and will soon unite with the half-nucleus already present. With the union of the two fertilization will be accomplished. Two additional sperm-cells are arrested in the capsule. 4, Two cells which have arisen by the cleavage of the fertilized egg. They are still within the old envelope. 5, The next—or four-cell—stage.

parents. A truth which needs particular insistence is the following: that the growing embryo is not in the best sense a part of the mother, but from the moment of fertilization a new individual. The mother serves the child before birth, much as she will later on, by giving it protection and food. It will be appreciated that this view does not en-

courage any great faith in the current stories of prenatal impressions.

The Sex of the Offspring.—Many different views have been held as to the reason why the numbers of individuals of the two sexes turn out to be so nearly equal. The following explanation is probably to be accepted. An ovum prior to fertilization is of an indifferent type, it has no tendency to develop a male or a female embryo. The spermatozoa are of two kinds—one type will produce a male from the neutral egg while the other will beget a female. If these two sorts of sperm are released from the testes in equal and enormous numbers, the chances will favor a close balance between the sexes. People have greatly desired to control the sex of their children, but the prospect of this is not at all bright. As a matter of fact, boys and girls are not born in precisely equal numbers; about 104 boys are found for 100 girls. It is remarkable that this inequality tends to disappear in any generation, because the mortality among boys is slightly higher than among girls.

We have said that a fertilized ovum is chemically different from one which has escaped fertilization. An important result of this difference is the adhesion of the former to the lining of the uterus. If it is to be retained in the body of the mother and undergo development this attachment is evidently essential. Infertile eggs do not anchor themselves to this surface, but those that have been impregnated become fixed at some point upon the uterine wall. This lining sloughs and is renewed in connection with each menstrual cycle. It is supposed that this elaborate preparation has to be made each month for the possible implantation of an ovum.

The immediate result of the union of the male and female nuclei is a remarkable impulse toward cell-division. We have said repeatedly that an unfertilized ovum is only half a cell, and that the same is true of a sperm. When the two have coalesced we have not only a complete cell in place of two halves, but it is a rejuvenated cell, "young" in its active tendencies and in the light of its potential career.

We may safely conclude from what we find in the egg of the star-fish and other forms that fertilization is promptly followed by the cleavage of the egg into two cells. In this act of partition, as in others that come later, the nuclear substance which seems so significant is divided with scrupulous accuracy.

Twins.—It may happen that two ova are exposed to fertilization at one time. If the double conception is accomplished, two embryos may find space for their development in the uterus. The children that are born may be of opposite sexes and their resemblance may not be striking. Twins that are "identical"—being of the same sex and wonderfully alike in the smallest features of their organization—probably have a different origin. These are believed to have come from a single ovum. After the first cleavage has taken place some mechanical influence has separated the cells and—marvellous to relate—each one of them has shown the power to form an entire human body. Identical twins are said to be alike even to the lines on their fingertips.

The first cleavage is soon followed by a second which results in the formation of four cells. The plane of the second division is at right angles to the first. A third cleavage in a plane perpendicular to both the first and the second gives rise to 8 cells. Additional cleavages convert the cluster of cells into an aggregate suggestive of a berry with its numerous lobules. Of course, until some new substance is added, the embryo cannot exceed the size of the ovum from which it has been evolved: its cells must become smaller and smaller as their number increases. Sooner or later nourishment begins to be received from the maternal blood and secretions. By degrees the placental system described in Chapter XVII comes into existence. But it remains true that, however much the bulk of the new organism is enlarged, its every cell is a lineal descendant of the fertilized egg and the two parents are equally influential in shaping its destinies.

The normal term of development (*pregnancy or gestation*)

in the human is ordinarily given as 280 days. This is equivalent to 10 menstrual cycles. Children born at the end of 8 or 9 of these cycles may survive, and it is of interest to note that birth is more likely to occur at these times than at intermediate dates. During pregnancy the usual signs of menstruation are not in evidence, but there is still a latent rhythm in the system.

At the end of the full term the unborn child (*fetus*) has reached an average weight of about 7 pounds. The uterus has enormously enlarged to make room for the child, and is, in fact, even larger than might be supposed, because the fetus is surrounded by a considerable quantity of fluid together with enclosing membranes and the placental disc. The fluid leaves all parts of the growing body free to develop without encountering hindrances by reason of pressure. The uterus has, early in pregnancy, escaped from the rigid confinement of the pelvis and risen high into the abdomen. Its opening is obstructed. The nutritional requirements of the mother during these months will be seen to be high, and especially as regards the materials necessary for the promotion of growth. It is not the child alone which has to be considered, but the temporary increase in the mass of the uterus, the accessory structures, and also the mammary glands which are preparing to secrete milk. The harmonious advance of these associated processes is probably secured by the action of internal secretions proceeding from the cells of the ovary and from the embryo itself.

Birth.—The separation of the child from the body of the mother means that it is removed from a sphere of automatic care and protection to one in which these duties are consciously and intelligently performed. It is at the same time the beginning of responsible living for the baby. Theoretically the process is a simple one. It is effected by contractions of the smooth muscle of the wall of the uterus, reinforced in the later stages by strenuous employment of the abdominal muscles and the diaphragm. The first result of these activities is to dilate the neck (*cervix*) of the

uterus to make way for the descent of the child. At a variable time the membranes are broken and the fluid is released. Gradually, with labor and suffering, the child is urged through the ring of the pelvis and the external opening of the genitalia. Its delivery is shortly followed by the expulsion of the placenta. The ordeal of child-birth is a severe one, but it should be viewed as a normal and not a monstrous event. Happily, its pains and dangers have been greatly lessened by modern medical skill.

It is easily possible to exaggerate the changes which come to the baby at birth. One should not think of it as suddenly and mysteriously "coming to life" at this moment. It must indeed begin to breathe for the first time, and the alimentary tract is now to be brought into use, but in many respects the bodily activities continue much as they have been. The heart has been beating from a very early embryonic period. Impulses from the central nervous system have frequently flashed to the skeletal muscles and called them into aimless play. The unborn child has been shielded against heat-loss through being enveloped by maternal tissues having its own temperature; in large measure this protection has to be continued in early infancy. More than one writer has suggested that the sleep of the newborn corresponds closely with the condition before birth.

Heredity and Conduct.—The momentous and fascinating subject of inheritance has been investigated of late with a thoroughness never before possible. The literature is large and much of it is difficult reading. The salient facts have been gathered in two or three books¹ to which reference may be made. Only one question can receive any attention here. This is that most serious and haunting one which every young man is bound to ask. How far does my conduct bear upon the welfare of the children I may have? Will they be stronger and better because of discipline I have imposed upon myself? Will my indulgences set limits to their self-control? If a man

¹ See references, p. 414.

has a simple faith in such a relationship it certainly affords a strong and fine motive for right living. The facts admit of a somewhat different interpretation, without, however, weakening the moral obligation.

There are good reasons for believing that the germ-cells which are found in the mature individual are descended from cells set apart at a very early stage for their peculiar purpose. Their ancestors have never been anywhere but in the gonads. They are thus comparatively unaffected by accidents that befall other parts of the organism. The assertion is current that "acquired characters are not inherited." This is evidently true of gross mutilations. It is certainly comforting in time of war to be assured that the devoted young women who marry the pitiful wrecks of battle do not sacrifice the coming generation by their course. Their children will be such as the same parents might have had if the fathers had never suffered wounds. The germ-plasm has been protected as a priceless treasure.

To injure the offspring the hurtful influence must be brought to bear directly upon the tissue thus set aside. Such an injury would seem to be a possibility if the agent should be a chemical agent transmitted by the body-fluids. This is generally held to be a condition realized in the case of alcohol. The poison being admitted to all parts of the system can find access to the ovaries and testes. It can definitely damage the all-important reproductive elements. It is the common tradition that the result is an inherited craving for liquor, a fatal weakness in the presence of this temptation. But this is not borne out by the facts. The injury to the stock may appear in the form of epilepsy, feeble-mindedness, or in still other ways.

What is maintained for alcohol is believed to be true of the poison of syphilis. Here, again, is a chemical agent which is not confined to a particular region of the body but is widely disseminated. There is abundant evidence of the shocking deterioration of stock under its influence. If we now return to the earnest question of the young man, we can obviously say with all possible emphasis that the two

chief forms of intemperance, the alcoholic and the sexual, balefully threaten the welfare of the children.

What shall be said of less flagrant irregularities of conduct on the part of the parent? Is he to think that frequent failures to govern his temper are preparing the way for similar lapses in the next generation? Has he ground for hoping that habits of concentration which he may cultivate will add to the efficiency of his sons and daughters who are to be? Will simple laziness lower the physical standards of the offspring? Belief in such consequences of one's behavior is undoubtedly wide-spread. It is hard to see that it can have any but good results. Yet, as we have hinted, an alternative statement may be suggested.

Let us take the specific case referred to above: the loss of temper. A man's life is disfigured by outbreaks of this kind and years later his son's irascibility constantly recalls the father's. The moralist may say that the father allowed a character to develop which passed in an intensified degree to the boy. Another explanation is probably more just. The hereditary qualities of a race or family are so stable that they are scarcely modified by the events of an individual life. The father's explosions of anger have not given fresh momentum to the underlying tendency, but they have most clearly indicated what the tendency is. The boy starts about where his father did; a common inheritance is behind them both, and it is this community of descent which we should dwell upon rather than the succession of one life to another. They have inherited as brothers from one ancestry—though more correctly, as has been said, "as half-brothers having different mothers."

Shall we conclude that what we do is of no significance to our descendants so long as we do not grossly poison the germinal reserves? It is not necessary to express the situation so recklessly. Our lives are filled with the sense of struggle, and, as we review them, we regard certain episodes as victories and others as defeats. Perhaps the victories have not so definitely added to our strength as we like to think, but they have again and again shown that we pos-

sessed such strength as an emergency required. So they afford ground for confidence that our children will find themselves as well equipped for duty. If, on the other hand, we have to confess to many failures and unwise choices, we need not think that the stock we represent is much worse because of our sorry performances than it was at the outset. But we are bound to admit that it has not turned out to be a good strain, and we face the serious question as to whether it deserves to be perpetuated. Unfortunately the people who most need to ask this question are the least likely to do so.

This matter-of-fact account of human reproduction has done scant justice to the wonder of the process. The mystery of it has been oppressively felt, even from the day when the Psalmist wrote, "Thine eyes did see my substance, yet being unperfect; and in thy book all my members were written, which in continuance were fashioned, when as yet there was none of them" (Psalm CXXXIX, 16). Two minute bits of living matter are united, and from the time of their union they are able to mould to a certain type of organization an increasing mass of material. Eventually the new organism is so large that the ovum and sperm seem infinitesimal by comparison, but their stamp is on its every part; they have "leavened the whole lump." And within the maturing body there are already set apart the representative cells of the new blending, different in their capacities from all other germinal elements that have ever lived.

The student always feels like asking how such potentialities can be compressed into the microscopic compass of the egg or the still smaller sperm. No one can pretend to consider that this is an easy conception. We may, nevertheless, make the fact seem more reasonable if we make allowance for the possibilities of what is called by the organic chemist *stereo-isomerism*. The master of this difficult subject well knows that numerous compounds with clearly individual properties may exist, even though all the members of the series have the same composition as deter-

mined by analysis. The great variety realized in such a series is accounted for by assuming that the molecules are differently constructed; they contain the same atoms, but the grouping is not the same. The more complex the molecules with which we have to reckon, the larger the number of ways in which their constituent atoms can be arranged.

The molecules which have to do with the transmission of hereditary qualities are presumably of the protein order or nearly allied thereto. The number of ways in which the atoms of a protein molecule can be combined is, to all intents and purposes, infinite. It may be that we can satisfy all the demands of a theory of heredity without introducing any factor but the spatial ordering of the atomic clusters and chains. Supposing this pattern to be modified at the time of fertilization, we can see that the mathematic chances are entirely favorable to a unique product and not to a repetition of anything that has ever existed before.

CHAPTER XXX

SOME MATTERS OF HYGIENE

A chapter on the Hygiene of the Nervous System has found a place in this book and also one on the Hygiene of Nutrition. Other suggestions regarding the right use of the body have been dropped from time to time. It may be well in conclusion to assemble some of the fundamental principles in the form of a summary. When this is undertaken it is a distinct advantage to have all the topics which we have treated as a background—to correlate our hygiene with our physiology.

Vitalism and Mechanism.—Living matter is sharply distinguished in many ways from lifeless. The contrasts are so evident that men of science formerly believed that very different principles must be effective in the two states. Organisms were supposed to transcend some of the limitations of inorganic bodies. The teaching that they are thus superior to what are called the laws of nature is known as *Vitalism*. The contrary doctrine, that they are strictly limited by these laws, that they are machines transforming energy which they neither create nor destroy, is called *Mechanism*.

We have seen that the experiments made in laboratories for the study of metabolism show that animals and men are rigidly subject to the principle of the conservation of energy. The modern tendency has been to emphasize this subjection to fixed limitations, and it is certain that experimental progress has been based almost wholly upon faith in its validity. Our objective studies must be conducted upon organisms or parts of organisms in the hope that we may find uniform responses to the conditions we establish. If we cannot find the regularity of

behavior which is the characteristic of a mechanism we can learn nothing that is significant.

At the same time, it may be acknowledged that the early mechanists were cocksure and oversanguine in the expectation that they could analyze all the reactions of animals with ease. Animals may be machines, but they are inconceivably complex and correspondingly removed from ready comparison with machines of human construction. The most baffling complexity is evident in the constitution of every cell, and when cells are associated in enormous numbers the difficulty of making predictions in regard to the capacities of the organism is increased according to a mathematical formula.

In the light of all that is known we may choose to emphasize either the resemblance of the organism to a machine or its dissimilarity. One may be a strict mechanist or a "Neo-vitalist" as one assumes the former attitude or the latter. The neo-vitalist is impressed with the wonder and mystery of life, but so far as he looks for additions to our knowledge he approves the methods and deductions of the mechanist. The mechanist must also have his moods of marvelling and so the two are not so far apart as is sometimes assumed. The ultimate question of the relationship of consciousness to organic matter seems unanswerable.

This discussion of the scientific point of view has been introduced because it bears directly upon one's estimate of hygiene. If the body is in any real sense a mechanism it is fair to insist that it be cared for systematically. If it is superior to all the limitations of a mechanism it may be superfluous to give time and thought to its care. "Living on one's nerve" may be noble in this case but it is clearly reprehensible according to the mechanistic conception. We shall adhere provisionally to the idea that the body is a machine, unique in its power of self-repair, but so limited in this and other respects as to impose the obligation of careful conduct upon the individual.

Mental States.—At the present time much is said of the importance of mental states for the maintenance of health and for its restoration when it has been lost. Do we deny the force of this claim when we take a mechanistic position? We deny certain sweeping assertions but we continue to assent to a moderate application of the teaching. There is a clear correlation between mental serenity and the harmony of physiologic activities. There is room for argument as to which is primary and which secondary in a given case. Most men take it for granted that the mind reflects the condition of the body, and the body the mental content. It is prudent to avoid the metaphysical discussion and lay stress only upon the parallel between the two.

Sometimes an enthusiast will declare that "if the mind is right the body will be." Another may retort that "the mind is not likely to be right unless the body is sound." This is arguing in a very small circle, and it has but one useful result, it suggests the wisdom of approaching the problem from both sides. Sweeping generalizations are ill-advised. Shall we be so presuming as to pass judgment upon many of the finest men and women who have ever lived—Scott, Darwin, Stevenson, and Mrs. Stowe, to mention no others—because they have been physically infirm?

If we can lead a man who is obviously ill and depressed into a confident and benevolent frame of mind it is likely enough that many of his symptoms may be relieved. The turning point may be passed and his recovery go forward from that hour. Since this practical possibility exists it is not important to decide whether the mental state is causative or whether it is symptomatic. It is held by some to *occasion* the desired adjustment of the nervous system and by others merely to *attend* it. Whichever it is it gives us something to work for in contending against illness in ourselves or others. It need not lessen our respect for material measures of treatment.

A word should be said here about the various schools of therapeutics which exist side by side and seem to minister with such success to human infirmity. It may be

affirmed that each system succeeds, so far as it is found to do so, by reason of the merit that is in it. This is equally true whether the practice is mental, mechanical, or pharmacological. Each is wrong in denying virtue to its competitors. The regular practitioner stands superior to all who have allied themselves to peculiar and exclusive systems, recognizing well the elements of good in each though regretting the bigotry which their exponents display. He is constantly blamed for withholding his endorsement of measures which have proved valuable. Such measures he might be ready to commend if he were not thereby committed to the denials as well as the affirmations of his rival.

The old trust in drugs is not widely prevalent to-day unless among rather ignorant people who form the clientele of the makers of patent medicines. A good many people underestimate the occasional utility of drugs. But it is a sound principle that a drug is for a definite emergency, or for an incurable condition, and that it is not to be substituted for hygienic living. As was said of cathartics, so it may be said of headache cures, cough syrups, "tonics," and other preparations that the occasion for their use should likewise be an occasion for reflecting how a recurrence can be avoided.

If we attempt to name the great requisites of living in health and efficiency we may make a list somewhat as follows. First of all, the inheritance must be sound. This, unhappily, lies outside the choice of the individual. He has it to consider as he in his turn contemplates becoming a father. Second, we must have successful nutrition; we need not renew our discussion of this subject. Third, the activities must be balanced and rest must be adequate. Fourth, the environment must be wholesome and intellectually stimulating.

Exercise.—We must enlarge upon the third requirement of the series. It introduces at once the topic of muscular exercise which could not be properly handled until we had outlined all the physiologic functions. It is related to all of them. The skeletal muscles are given

peculiar distinction by several facts. They form about half the entire body and they are the seat of a very large share of the metabolism. In the second place, they are under voluntary control; it remains for us to say how they shall be employed. We can drive or spare other organs also—for example, the digestive and the sweat glands—but there are none which we can so slight and neglect to exercise as these.

In a book like this we cannot enter into questions of the particular kinds of muscular activity appropriate to people of various ages and habits. We must limit ourselves to broad statements. It will be convenient to speak first of the effects of exercise upon the neuromuscular mechanism itself and then to show in how many ways its influence is extended to other systems. The object of exercise is sometimes training for special accomplishments and sometimes simply the preservation of the general health.

The most familiar fact in the mind of the schoolboy is that muscles grow with use. The increase is said not to be in the number but in the size of the fibers. The changes which accompany contraction are of a destructive kind, but it seems to be commonly true in biology that the compensation for a wasting process is, in a vigorous tissue, more than equal to the original loss of substance. It does not merely recover but it becomes larger than it was before. Of course an increase in the size of muscles means a gain in strength, but we should be very much in error if we were to overlook certain other factors.

It is altogether probable that betterment of quality is a more important result of training than sheer gain in mass. We can easily think of persons whose muscles are insignificant in appearance but whose endurance is remarkable. Several conditions can be suggested which they probably exemplify. First, their muscles are superior in a chemical sense. Second, the circulation is advantageously directed to give them support. Third, the blood itself comes to them with a favorable com-

position--not impaired for service by the presence of poisons either derived from the intestine or from the metabolism.

Efficient muscles must also be distinguished by efficient innervation. The best possible end-plate transmission may be assumed. Another feature may be a more general employment of the units than is secured by the untrained subject. It may be that a muscle which seems less strong than we should anticipate in view of its size is one in which there are many idle fibers. Finally, the working capacity of any set of muscles must depend upon the organization of the central nervous system and the manner of using it.

Let us emphasize the idea just advanced. It means that efficiency depends upon coördination, for coördination is secured through the interrelations of the neurons in the cord and the brain. The attainment of skill and ease comes with the establishment of these associations. The cerebellum as well as the cerebrum must be involved. Only very lately has it been appreciated that the afferent as well as the efferent mechanism must be credited with a share in pushing motor resources to their limit. The matter is too involved to be presented in full but a paragraph may be given to it.

We have only to add one more step to a familiar series. If we try to make a list of the factors on which the effective power of a muscle depends we shall parallel the enumeration above. We shall think first of the muscle's own size and nature. Then we shall recognize the limitation imposed by the end-plates and then the dependence of these for stimulation upon the motor centers of the cord. These are played upon by impulses from at least two sources: those that come from the receptors, as in the production of simple reflexes, and those which come from the cerebral motor cortex. We might well mention the impulses from the cerebellum also.

Now a spinal center may be supposed to transmit impulses with a maximum effect when it is beset from as many angles as possible, when all the available means of

excitation are combined to bear upon it. The same will apply to the motor centers of the cerebrum; these are not self-stimulated, but depend on other elements to induce reactions through them. It follows that muscles must give their best performance when the governing centers are subjected to the most multiplied stimulation and this includes potentially the whole receptor system. In other words, one reason for the power of the athlete is his responsiveness to what he sees, hears, and feels—the excellence of his afferent equipment.

We find that fatigue is greatly delayed when we are doing something that we enjoy. Our enjoyment is probably a measure of the richness of the afferent tides in the nervous system and if we suppose that these currents are applied in reflex fashion to secure innervation of the muscles we have a simple explanation of our own endurance. Dancing would be harder work than sweeping a room if the comparison were not entirely destroyed by the superior means of stimulation which accompany it.

Other Effects of Exercise.—We may now turn from the value of exercise as a way to improve the command of the motor apparatus and mention some of its influences upon other systems. We may pass over the respiratory features which have been given a place in Chapter XXI. Something must be said of the effects upon the circulation. We may distinguish conveniently between those that relate to the heart and those that can be classed as vasomotor.

The heart is exercised whenever the skeletal muscles are actively used and the demand upon it is roughly proportional to the intensity of the effort. There is no other way to give this organ vigorous use. If it is sound in the beginning it responds to training like any other muscle, growing somewhat more massive and much more hardy with exercise. It is to be noted that a heart may become larger than normal in two different cases: the increase may be in the thickness of its walls or

in the volume of its cavities. The first is *hypertrophy*, the second *dilation*. A hypertrophied heart is usually of exceptional strength, while dilation without reinforcement of the walls is an undesirable change. Some evidence has been brought forth to show that athletes' hearts do not hold out well in later life, but this is denied. It lies rather outside the present argument which is in support of moderate rather than athletic activity.

The vasomotor reactions which attend muscular contraction are perhaps sufficiently clear. The vessels of the muscles are dilated and so are those of the skin. There is probably an offsetting constriction in the digestive tract. The adjustment becomes more positive and timely with practice. The sedentary person lacks the capacity to make this prompt adaptive change in the distribution of the blood. His vasomotor system lacks resilience and it cannot be relied upon to make strong corrective reactions in the interest of health.

The vasomotor effect of a cold bath is of a similar nature. When the skin is chilled, the blood is sent to the internal organs in increased quantity. This primary diversion is the reverse of that when exercise is begun. But it is followed by a hardening of the muscles accompanied by a heightened metabolism. The heat-production of the body is augmented and when the subject leaves the bath and begins to rub down there is surplus heat to be thrown off. The vasomotor reaction is then in the same direction as in exercise and the occasion is really the same.

Muscular contractions directly promote the movement of the blood aside from the enlistment of the heart in their support, provided only that they are rhythmic rather than sustained. When a muscle grows tense, it thrusts the blood out of its own veins. Other veins are caught and squeezed between neighboring muscles or between muscles and the skin. The veins of the extremities, in which such action is most marked, are provided with simple valves so placed as to allow no backward movement of blood toward the capillaries.

Hence the emptying of these veins always drives blood in the direction of the heart while they refill from the tissues. This accelerating influence is lost when long-sustained contractions are made, as in carrying a suit case.

The hastening of the blood-flow by the pressure of contracting muscles is a kind of massage and its effect is extended to the contents of the lymphatics. The fact has been noticed in Chapter XVII. There is every reason to believe that it assists in the removal of waste and promotes the nutrition of the regions where the condition is operative.

The beneficial results of muscular activity so far as they are manifest in the digestive system are indirect but important. The immediate consequence of activity must always be a withdrawal of blood from the alimentary canal. This cannot, in itself, be other than a hindrance to the processes going on there. It is likely that excessive perspiration leads to a shrinkage in the volume of the juices. But in spite of these unfavorable features we know that the net outcome is in favor of the man who takes a fair amount of exercise. To some extent his digestion may be helped by the actual agitation of the canal. A far more significant reward is the sharp appetite which usually presages a successful disposition of the meal.

The Fundamentals of Sex Hygiene.—Here is a matter which is much more widely and freely treated now than it was a few years ago. There must always be an inclination to reticence on the subject and for the best of reasons. The abnormal side of sexual life is abhorrent to normal individuals. The normal side is limited to the sacred intimacy of marriage and should remain inviolate. But there are a few cardinal principles of thinking and conduct which it cannot be an offense to publish.

The sexual instinct in the average man is a compelling one. This being true, it is plainly his duty to see to it that it shall not progressively encroach upon the sphere of other interests. This is precisely what it will do if the line of least resistance is followed. There are men

everywhere whose thoughts revert to the subject of sex whenever they are free to wander. Their ideas of enjoyment and humor are sexual. It is probably true of men of stronger character that most of them wish that the matter had not become so obtrusive. They regret that they have not more firmly confined it within bounds. Nothing else so threatens the symmetry, the efficiency, and the height of attainment of a man's life.

Clearly, then, it is the part of wisdom to occupy one's energies with many concerns which shall not minister at all to the impulses of sex. As a man who is sailing a boat places himself so that his weight shall tell against the heeling effect of the wind so one should be at pains to trim the craft in which he is making the voyage of life. To bring it upon an even keel he must match other forces against that which is always bearing him over to one side. To drop the figure, he must set himself tasks for the muscles and the intellect which shall keep sex in abeyance.

Appeals for sexual self-mastery in the name of good taste, chivalry, social justice, and even religion have genuine power. But we shall not set them forth at any length in this place. We shall be content to urge that the earnest cultivation of varied interests, the finding of pleasure in work and sport, the stimulus of friendships, and the appreciation of the aged and the little children as well as of our own generation will usually insure the relegation of sex to its own proper but restricted place. Habits (which may quite as well be mental as physical) which extend its dominion are calculated to lead on to the most unhappy distortion of ideals and to the forfeiture of the highest prizes.

Three concrete reasons—to go no farther—may be advanced for sexual abstinence on the part of the young man. First, the dangers of the venereal diseases suggest a motive, not high but positive, for continence. Second, if he indulges he becomes a contributor to the degradation and misery of outcast womankind. Finally, he should cherish the purpose of coming to his wedding-day with no

sordid and guilty memories, with a past as blameless as that of the woman who has put her trust in him. And let him realize that marriage itself is to impose denials as well as confer privileges.

What has been said will be not at all weakened if it is coupled with a protest against sexual squeamishness, the cultivation of the belief that the whole matter is base and evil. It is not well to quarrel in this way with a part of normal human inheritance. Specialists in nervous diseases find this unwholesome attitude linked with discontented and ineffective living; it often defeats its own purpose. What is to be striven for is not the annulling of instinct but its regulation; or, to use Richard Cabot's fine expression, its consecration. To say that the companionship of marriage should be on a high plane is to utter only a half-truth; it should, rather, be upon *all* planes.

Conclusion.—The plea that has just been made is for symmetry, for right proportion, for balance. By an extension of the same teaching to all of life we are brought back to the requisites of hygienic living which have been named. Given a body of normal potentialities, one's task is to nourish it, to set it to work and play, to grant it rest as needed, and to provide it with an environment favorable to its maintenance and activities. Discussion of the environment falls for the most part outside a text-book of physiology. We have touched upon one of its aspects in speaking of ventilation. Its larger problems draw our attention from the individual, who is central in physiology, to the contact of human beings in communities. This is the subject matter of works on Public Health.

It is most desirable that the reader who comes to the end of an account such as has been attempted here, dealing with the body living by itself, pass on to learn something of preventive medicine. He will find the story one of absorbing interest, rich in personalities and courageous achievement. He will come to realize how the relative security of life in our time stands contrasted with its uncertainty in all earlier ages and how bright are the promises for the future.

SUGGESTIONS FOR COLLATERAL READING

A few books may be named here which will be broadly useful as works of reference. After these have been mentioned we will make a list of sources relating to specific topics in the general order in which they have been taken up in the foregoing chapters. In this there will be implied the author's acknowledgment of his indebtedness to these books and articles.

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Chapter III.—For a parallel but fuller outline of anatomy: Hough and Sedgwick, "The Human Mechanism," Boston, Ginn, Second Edition, 1917, Chapters II and III.

Chapter IV.—For ciliary reversal: Parker, *American Journal of Physiology*, 1905, xiii, 1.

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Chapter VI.—For details of nervous tissue: Lickley, "The Nervous System," New York, Longmans, 1912.

Chapter VII.—For an interesting discussion of reflexes: Hough and Sedgwick, *loc. cit.*, Chapter VII.

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Chapter XVI.—Martin, *loc. cit.*

Chapter XVII.—Hough and Sedgwick, *loc. cit.*, Chapter IX. The physics of the circulation has perhaps never been so clearly presented as by Foster: any edition of his "Text-Book," New York, Macmillan.

Chapter XVIII.—Foster, *loc. cit.*

Chapter XIX.—Hough and Sedgwick, *loc. cit.*, Chapters IX, XVII, XXI.

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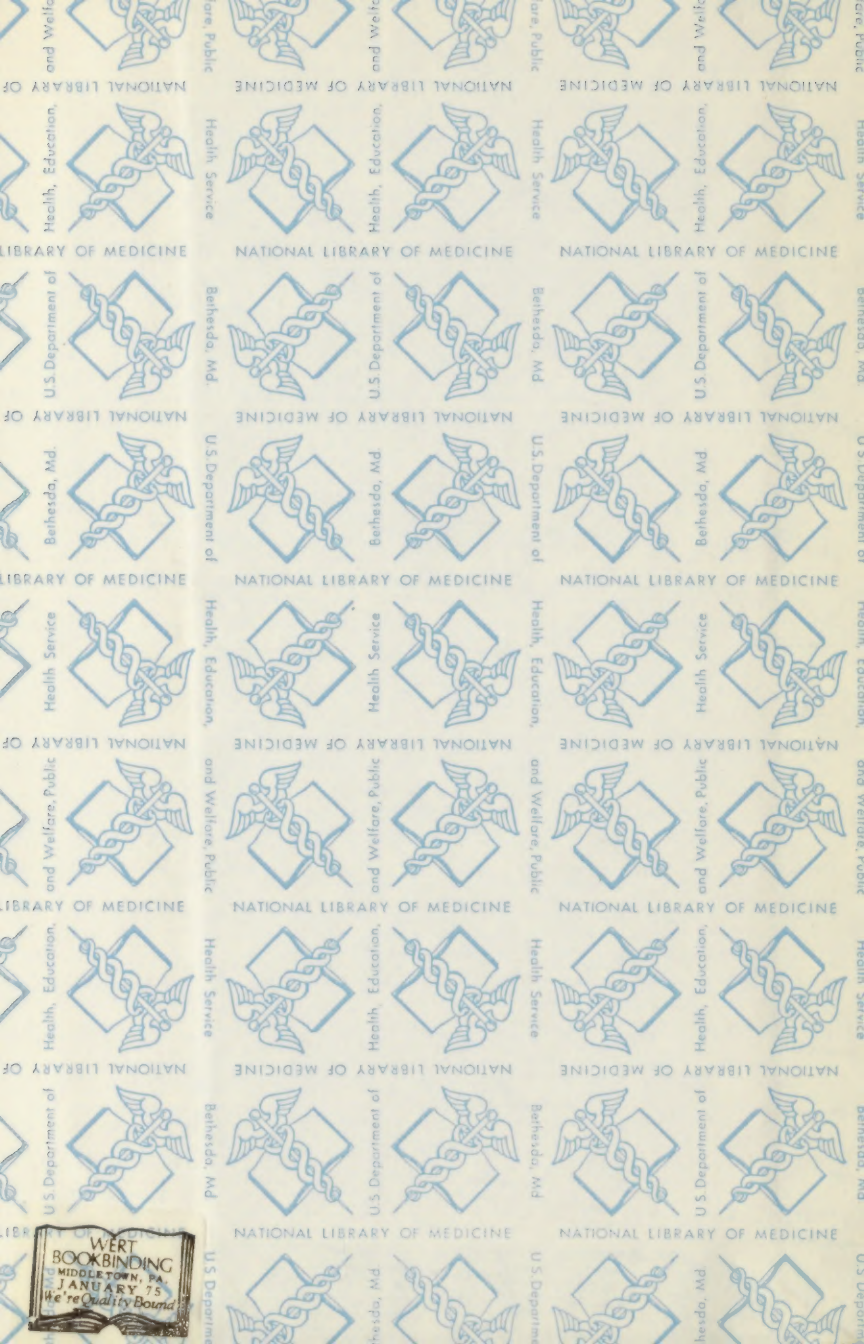
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